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INTERIM DEVELOPMENT REPORT

DATE— JAN 1953

Navy Department Bureau of Ships

Electronics Division

615

CONTRACT NObsr-52423 INDEX NO. NE-111[redacted]

Oklahoma A & M College

Electrical Engineering

Division of Engineering Research

Stillwater, Oklahoma

SECURITY INFORMATION

INTERIM DEVELOPMENT REPORT

ON

STUDIES TO DETERMINE THE RELIABILITY OF RELAYS
BUREAU OF SHIPS SPECIFICATION SHIPS-R-405

This report covers the period January 1, 1953 to January 31, 1953

OKLAHOMA A & M COLLEGE
STILLWATER, OKLAHOMA

NAVY DEPARTMENT BUREAU OF SHIPS ELECTRONICS DIVISION

CONTRACT NO. NObsr-52423 INDEX NO. NE-111406 1 MAR 1951

ABSTRACT

I. During this month, work was done on various problems related to standardization, relay characteristics, and specifications. For instance, a detailed study of contact bounce is necessary in order that a satisfactory definition may be made of contact bounce, the proper method of testing and measurement. These topics, in turn, will be used for definitions, standards, test procedure and specifications.

The material is subdivided into the following sections:

I. Contact Bounce
II. Relay Static Characteristics
III. Analysis of Vibration Machine
IV. Standard Relays
V. Letters about Reprint
VI. Digest of Papers

II. Professor D.L. Johnson and Mr. Jack E. Tompkins left on January 20, 1953 and planned to return February 1, 1953. The purpose of this trip was to confer with officials of different concerns relative to relay tests and relay standards. The different concerns were:

Collins Radio Corporation, Cedar Rapids, Iowa; C.P. Clare, Co., Automatic Electric Sales Corp. and Comar Electric Co. in Chicago. Phillips Control Corp. Joliet, Ill.; U.S. Air Force Officials, Wright-Patterson A.F.B., Dayton, Ohio.

PART I

PURPOSE:

The preliminary work shall be comprised of the following phases:

Phase 1 - Study of existing relays. -

(a) Determination of the categories, styles and characteristics of relays to be considered. Tabulate characteristics of a number of relays to show types, ratings, RF-AF or DC, function for which designed, size, time of operation, coil resistance, and other pertinent data. The Bureau of Ships will forward, from time to time, additional information as to types of relays being used in existing equipment.

(b) Obtaining from relay manufacturers all available technical data (including drawings) describing the physical dimensions, tolerances, and electrical and mechanical characteristics of each relay.

(c) Arrangement by types of this technical data from the various relay manufacturers into a relay catalog.

(d) Tests of existing and representative categories of relays to ascertain performance and check against the rated values.

(e) Study of tests presently conducted by relay manufacturers to determine what tests should be modified or improved to find the necessary characteristics to increase the reliability of relays.

(f) Devise new procedures for relay-testing as indicated by present needs; also devise new test procedures for determining more completely and more accurately the desired performance, with a view toward improving the reliability of relays.

Phase 2 - Study of failure reports (these failure reports shall be obtained from the Bureau of Ships) to ascertain, insofar as possible, the causes of failures, to tabulate the results, and to analyze the findings.

Phase 3 - A study to devise a method to make relay specifications consistent with actual required relay operation. Determination (based largely on relay manufacturers' technical data) of types and stringency of tests to be imposed on the relays under the specification draft to improve the reliability of relays under specific application.

Phase 4 - Arrangement of technical data, in a form to serve as a basis for an amendment to the specification presently under consideration.

Phase 5 - A study of relay characteristics and functions with the view of developing a new design of relay construction to improve the reliability of operation

CONTACT BOUNCE

As far as the writer is aware, an exhaustive study of contact bounce has not been made. There are references to the phenomena of contact bounce but it seems that very little has been published on this important subject.

It is interesting to note the statements on contact bounce in the various specifications. To cite a few examples:

"MIL-R-5757A

par. 3.10.5 Contact Bounce. No contact bounce shall be tolerated."

Under Scope and Classification

1.3 Class.- The relay shall be of the following classes, according to the operating shock range as follows:

Class 1. Capable of withstanding 50G shocks for 10 milliseconds, and 10 to 55 cps vibration without chattering."

There are two other classes listed.

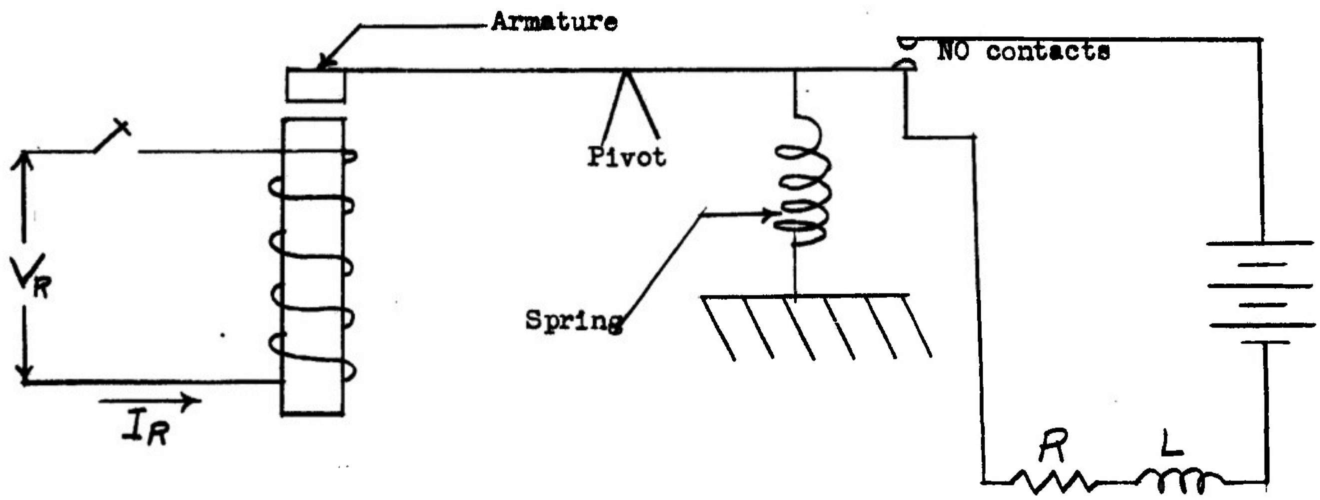
"MIL-R-5757B

par. 4.6.5.4 Contact bounce. Relays shall be tested to determine contact bounce. The method of test may be by comparing the number of make and breaks with the timing wave on the recorded chart of a GE Model PM-10-A1 oscillograph or equivalent means. The circuit shown on Figure 2 or other suitable methods may be used (See 3.20)."

Closing of A Relay

A study of contact bounce should be prefaced by an analysis of the closing of a relay. The opening will not be considered at this time. A relay consists of a coil which when energized causes the armature of the relay to move toward the core. This movement of the armature causes the contacts of the relay to close. The coil circuit of the relay and the contact circuit are not electrically connected.

A diagram might be of some assistance in this discussion.



When a voltage V_R is applied to the coil of the relay, a current I_R flows through the coil. This current establishes a magnetic field which attracts the armature of the relay and causes it to move toward the core. Contacts are actuated by the armature or are made of a part of the armature and when the armature moves to the position of where the maximum flux will be attained by the coil, the relay contacts will come together. The relay contacts are in another electrical circuit. The closing of the contacts causes current to flow in that circuit. The schematic diagram illustrates the physical factors involved.

The oscillograms of Figure 1, 2 and 3 were chosen to illustrate some of the ideas. The timing wave in each case was 1,000 cycles per second. The coil voltage is marked V_R, the coil current is lettered I_R, the contact current is I_C and V_T is the timing wave.

When a circuit is closed on a direct current source which consists of resistance and inductance in series, the current does not immediately arrive at the value as indicated by Ohm's law. The instantaneous value of the current as a function of time is given by

$$i = \frac{E}{R}\left(1 - \epsilon^{-\frac{R}{L}t}\right) \tag{1}$$

where E = impressed voltage

R = resistance of circuit

L = inductance of circuit

t = time in seconds

ϵ = 2.71828

As time goes on the exponential term inside the parentheses approaches zero as a limit and the instantaneous value of current approaches the value by Ohm's Law.

In the foregoing analysis, it has been assumed that the inductance of the circuit remains constant. In a relay, it is known that this assumption does not apply. The armature moves to the core after the coil has been energized, or the relay closes. During this time of movement of the armature, the current is building up in the coil circuit. The reluctance of the coil circuit has changed because the air-gap between the armature and the core has been decreased as the armature moves. The reluctance of the air-gap is

$$R = \frac{l_g}{A_{ag}\mu}$$

l_g = length of air-gap

A_{ag} = area of air-gap

μ = 1 for air.

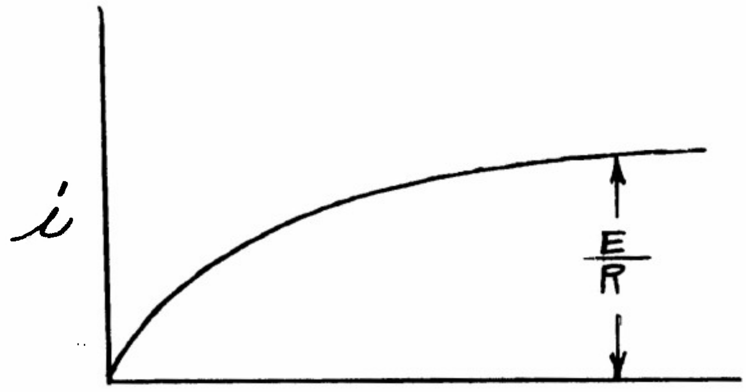
When the armature is open, the reluctance of the magnetic circuit is large and the predominant factor is the reluctance of the air-gap. As the air-gap is closed the reluctance decreases, until a minimum value is reached at the end of the armature travel. The final value of the reluctance of the magnetic circuit is then composed more of the reluctance of the iron core of the magnetic circuit.

The build-up of current in the relay coil is then influenced by two factors:

1. Build-up of current in a R-L circuit.

2. Change of reluctance of the magnetic circuit as the armature moves. The second factor also influences the first factor or, stated differently, the inductance is not constant.

Equation 1 may be plotted as below:



Equation 1 is for the specific case where the inductance is constant. In a relay, the inductance varies and therefore, the coil current will not follow equation 1, but will be somewhat different. Figures 1, 2 and 3 show the coil current, I_R which is different than the plot of the equation of the build-up of current in a R-L circuit.

The foregoing analysis indicates that an exact solution of the coil current is not possible. An approximate solution may be found but more information is required than the case of the series R-L circuit.

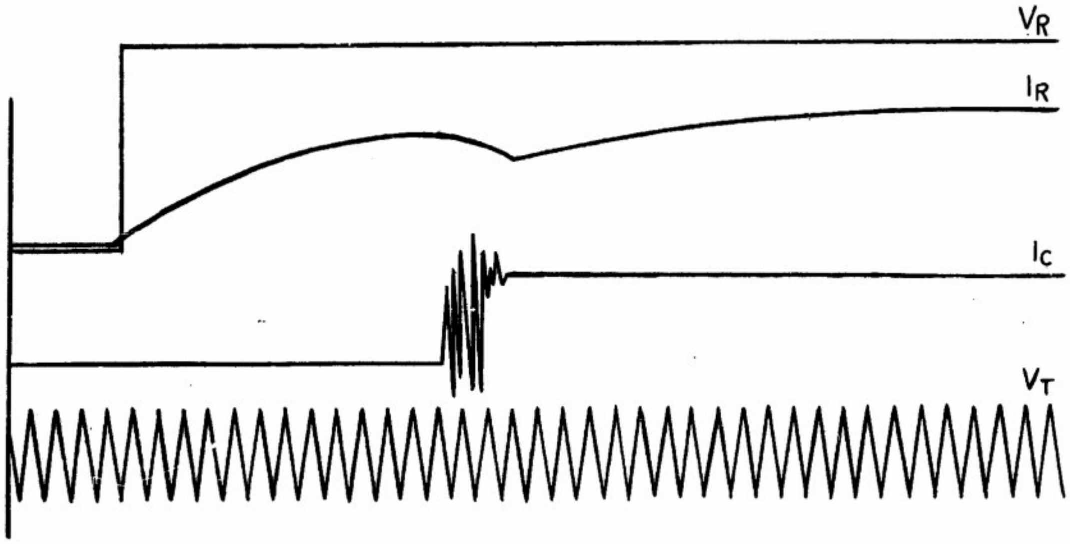


Figure 1

This oscillogram shows the voltage, V_R impressed across the coil of the relay. The trace of this voltage comes to its full value almost instantaneously when the switch is closed. The current, I_R, which flows in the relay coil does not reach the Ohm's Law value for some time after the contact current, I_C, has reached its final value.

The timing wave at the bottom is 1000 cycles per second. The time for complete operation of the relay is approximately 15 milliseconds. The time after the contact first moves to the closing of the contact is about 3 milliseconds.

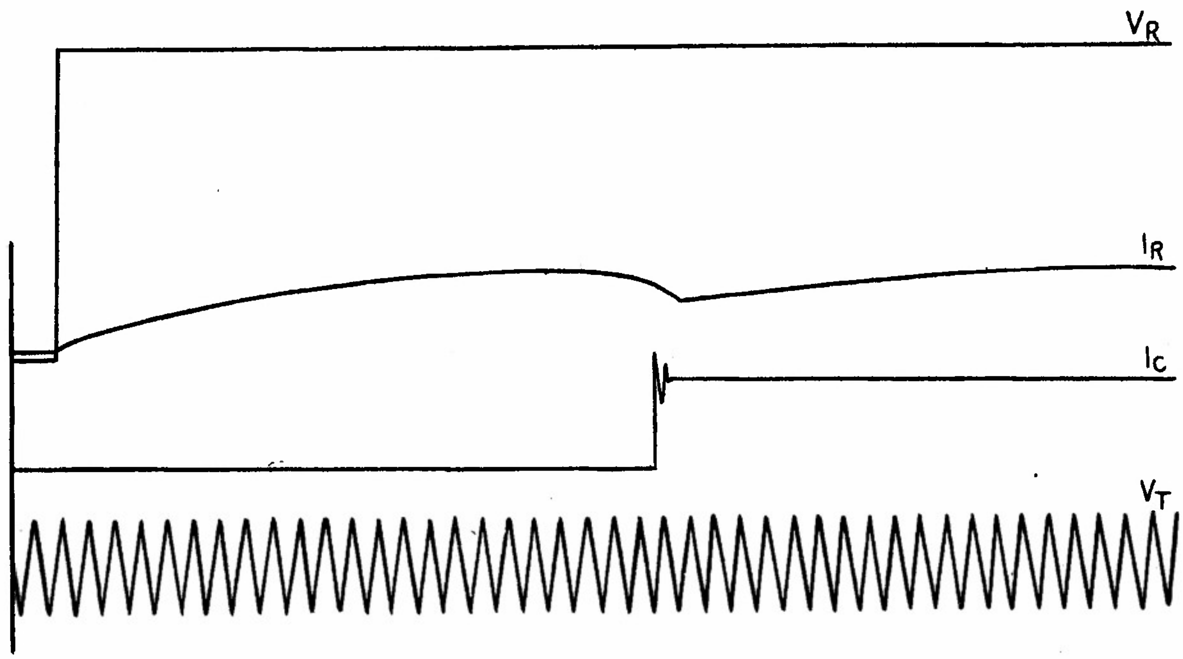


Figure 2

On this oscillogram, it is noticed that the time for the contact to move from the initial position to the closed position is comparatively short, or about 5 milliseconds.

The time for the armature to move is about 23 miliseconds.

The period of armature bounce is very small.

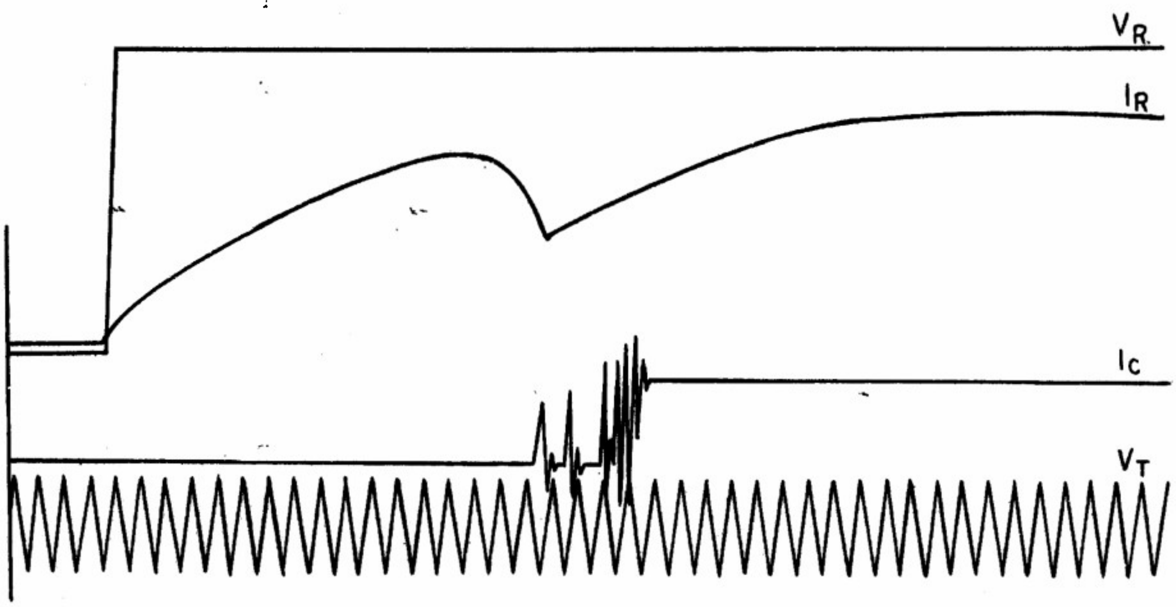


Figure 3

The coil voltage for this relay was 27.5 volts, the coil current was 97 ma. and the contact current, I_C, was 1.0 ampere.

After the contact starts to move, the coil current has not reached the Ohm's Law value but continues to build up.

There is considerable more bounce than that shown in Figure 2.

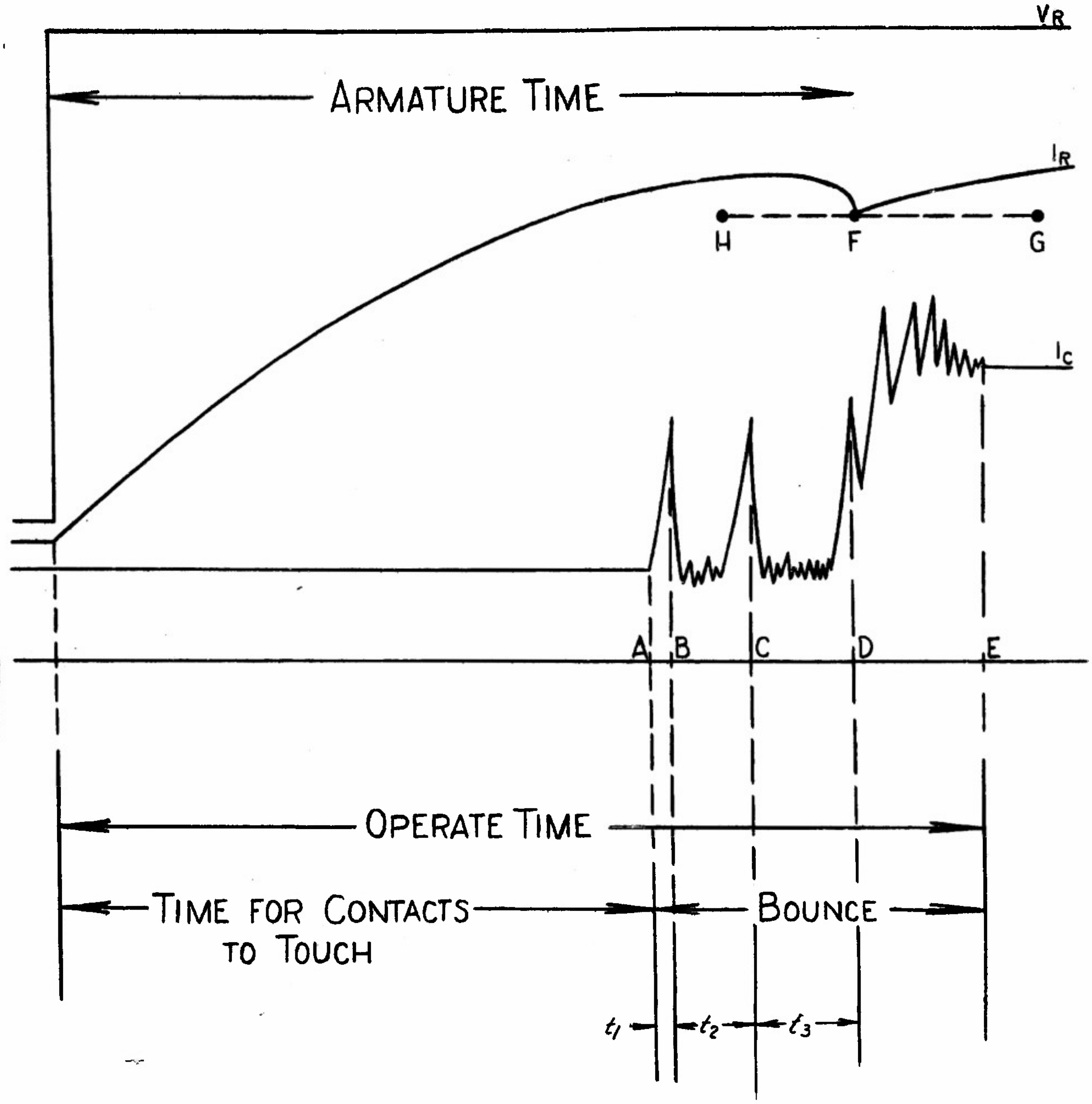


Figure 4

This is a diagram which shows some proposed definitions of the factors which are involved during the closing of a relay.

Oscillograms were obtained for three different relays. These are shown in Figures 1, 2 and 3. These three oscillograms illustrate the various factors which are involved in the operation of a relay.

A study of the coil currents for the different relays shows that the foregoing discussion is satisfactory for the first part of the curve. About the center of the trace of the coil current on the oscillogram there is a dip. This dip indicates the point at which the armature closed. The specific location of this point is determined by the particular design of the relay.

Figure 4 is a diagram which shows the varuous factors which are involved in the closing of a relay. It is an illustration which combines several of the features of the actual oscillograms of Figures 1,2 and 3. At the time when $t = 0$, the voltage, V_R, is impressed upon the relay coil. The coil current, I_R, tends to build-up. The armature moves until the contacts touch at point A. At the point E, the contact current, I_C, has been established and all transients have disappeared.

Bounce time may be defined as the time from A to E. The time from A to B or t_1 will be assumed to be the time required for the current to rise to the final value in the case where the contact bounce is zero. A comparison of the three oscillograms shows a considerable variation in the bounce and bounce time. In each case, the time required for the armature to move the contacts from their open position to the point where the contacts first touched was of a larger duration than the bounce time.

The operate time has been defined as the total elapsed time from the time the relay coil is energized until the contacts are closed and all contact bounce has ceased. The operate time is thus seen to be composed of the time for the travel of the relay contacts plus the time for the bounce of the contacts. Figure 2 illustrates a relay in which the bounce time has been reduced compared to Figures 1 and 3.

In some instances, an anlaysis of the bounce period should be made. For some applications, the time intervals, t_2 and t_3 may be of more importance than the fact of whether or not the bounce time is of some particular duration. For some control circuits where I_C controlled the firing of a tube, the intervals t_2 and t_3 might be in excess of that necessary and the tube might cease firing.

Point F on Figure 4 illustrates the limit of armature travel. The current, I_R, then continues to build-up as would be anticipated in a series R-L circuit. An examination of the other figures shows this might occur at H or G. In Figures 1 and 2, it is to be noted that point F is at a later time than the final closing of the contacts. Different follow-throughs for the armature and spring assembly would account for the difference. Follow-through is the motion of the armature after the contact has been made.

The oscillograms were made on a magnetic oscillograph and the oscillation of I_C has been questioned. Some values of I_C seem to indicate that the current is oscillatory. The circuit takes a D.C. contact current which reaches a steady value and this indicates that there is no series capacitance in the circuit. Doubt exists as to the cause of the oscillation of the contact current during the bounce period. It is possible that some or all of the oscillation may be caused by the mechanical system of the oscillograph. It is believed that a Cathode Ray Oscilloscope would be more desirable in that inertia of the moving system is not involved.

Opening of a Relay

The last section was concerned with the closing of a relay. Oscillograms were used to illustrate the reactions which took place.

This section will be related to the opening of a relay. By the term "opening" of a relay, with only NO contacts, is meant that the contact circuit breaks or opens a load circuit. This breaking of the contact circuit is caused by deenergizing the coil of the relay.

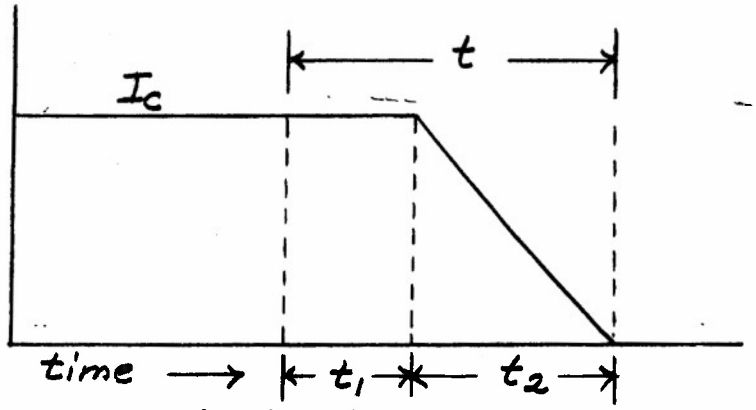
Relay contacts are held together by spring pressure. The force on the contacts, the contact shape, the contact material, and separating speed are factors which influence the change of the contact current from the steady state value to the zero value.

As the pressure on the contacts is decreased, the contact resistance increases. By the time the contact pressure is zero the contacts will be moving apart. The flow of current will be interrupted by interposing an air-gap in the circuit. For extremely small air-gaps, the tendency of the current will be to continue to flow. The air between the contacts breaks down (or becomes a partial conductor or an arc forms). Pitting of the contacts may be caused by serere arcing. As the distance between the contacts is increased, the resistance becomes very large and the arc is extinguished. An inductive circuit which is interrupted by the opening of contacts will cause a more pronounced arc and as a consequence more burning of the contacts.

There are no oscillograms to illustrate the idea of opening of relay contacts. The following diagram is an attempt to predict what takes place in an electric circuit under those conditions. It will be assumed that the contact circuit does not have an appreciable amount of inductance or capacitance.

In the figure, it is assumed that the total opening time is t; the time interval, t_1, is the time required for the armature to travel until the current starts to change in the contact circuit. The time, t_2, is the time required for the current to change from the rated value to the zero value.

There is some difference between the opening and closing of a relay as has been considered in this discussion. In the closing of a relay (refer to Figure 4), the time required for the relay contacts to move until they merely touched was a considerable portion of the closing time of the relay. The factor is not considered in the opening of a relay. In the diagram only two short intervals have been considered and the circuits have further been assumed to be entirely resistive.

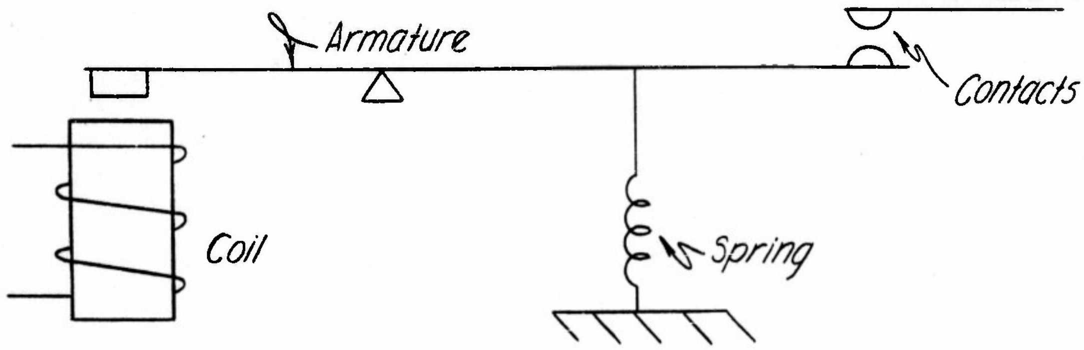


Opening of a relay

Since oscillograms are not available which show the foregoing, no further attempt will be made to analyze the reactions which occur.

Contact Bounce

The mechanical system of the armature of the relay may be a contributing factor in the cause of bounce in a relay. This mechanical system may be represented by a diagram as shown below.



When a current is caused to flow in the coil, the armature is attracted toward the core of the coil. The air-gap is small and the spring tends to hold the armature in the open position.

Most of the armature motion is taken up before the contacts meet. Some additional travel is allowed in order for the contacts to be under pressure during the time that the armature is closed. When the coil is deenergized the spring pulls the armature into the open position.

For ideal operation, the armature should close the contacts instantaneously after the coil has been energized (unless delayed operation was required) In any event, the making of the contacts should be such that after they touched, the pressure would be sufficient that a satisfactory circuit was established. In many instances, the ideal case is not reached. The armature is pulled toward the core of the coil which it strikes and then rebounds. Under some conditions the armature will oscillate, bounce or move back and forth between the mechanical limits set up in the relay.

Numerous factors are involved in armature bounce, such as: the stiffness of the spring, the mass of the armature and the friction. Vibration of the armature mechanical system may be compared to the resonance of a R-L-C circuit. With the proper values vibration, oscillation or resonance may result.

Again, if ideal operation were to be secured, the movable contact should move to the stationary contact and be held in that position until the coil was deenergized. There would be no making and breaking of the contact circuit, or there would be no bounce. The voltage applied to the coil, the spring, the mass of the armature, the air-gap and possibly other factors, all influence the bounce in a relay.

Much more attention should be given to this subject. An intense investigation of bounce should include an analysis, tests and new methods of design.

SECTION II

RELAY STATIC CHARACTERISTICS

RELAY STATIC CHARACTERISTICS

The equation for the force on the armature of a relay per sq. in. of armature cross sectional surface is

$$F = \frac{0.142\ (NI)^2\ 10^{-6}}{\ell^2} \qquad (1)$$

Where:

F = Force in pounds per sq. in.
IN = Ampere-turns on coil.
ℓ = Length of armature-pole air gap in inches.

For a particular relay the above equation may be written in terms of the power in watts consumed by the coil rather than in terms of ampere-turns Multiply both numerator and denominator by R, the resistance of the coil, and separate $(NI)^2$ into N^2I^2 giving

$$F = \frac{0.142\ N^2I^2R\ 10^{-6}}{\ell^2 R} \qquad (2)$$

Setting $W = I^2R$ gives

$$F = \frac{0.142N^2W\ 10^{-6}}{\ell^2 R} \qquad (3)$$

Equation (3) may be used to plot the force on the armature per sq. in. versus pole air gap for various constant values of power input. The curve obtained for any one value of power input may be thought of as a static operating characteristic of the relay. It should be noted that under actual operating conditions the relay usually operates during the transient build-up period of the coil current. Hence the power input is not constant but increases from zero to rated value during and shortly after relay operation. The dynamic characteristics of a relay are then entirely different from the static characteristics mentioned above. While the static characteristics do not represent dynamic operation of the relay, they may be used to advantage in studying certain chracteristics of the relay before and after operation.

To determine the static characteristics experimentally it would be necessary to physically restrain the motion of the armature. With the desired watts (or ampere-turns) supplied to the relay, the armature could be held stationary at various values of pole gap while the net force on the armature was being read from a guage or scales.

For purposes of illustration, a relay coil having N = 2150 turns, R = 30 ohms and I = 0.2 amperes was selected. Using these values, equation (3) reduces to

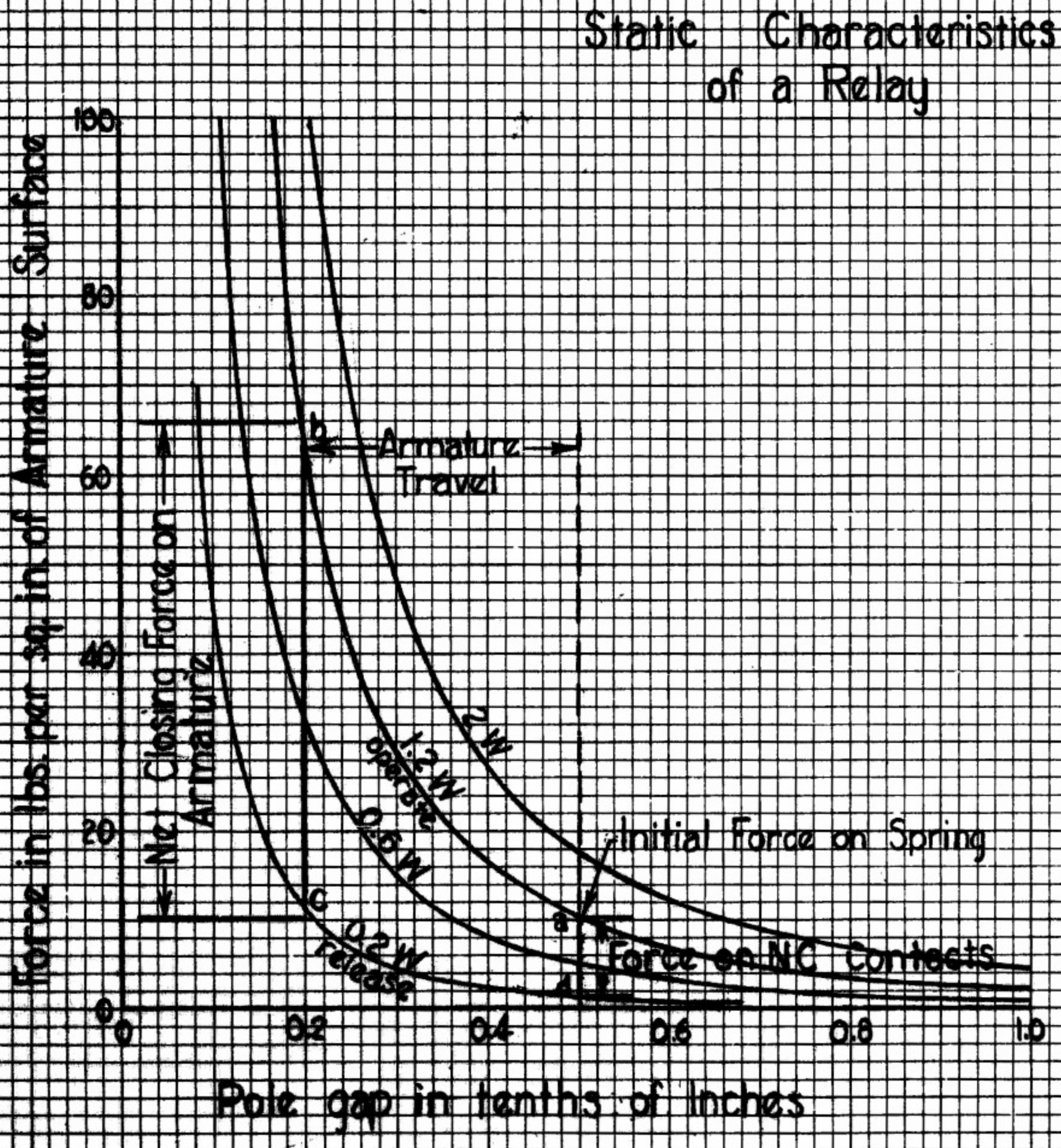
$$F = \frac{0.0219W}{\ell^2} \tag{4}$$

The rated coil power is $(0.2)^2 \times 30 = 1.2$ watts. Static characteristics for values of W equal to 2, 1.2, 0.6 and 0.2 watts are shown on the following curve sheet.

To analyze the relay operation as indicated on the curve sheet, it is perhaps better to start with the relay in a deenergized position, i.e., with the armature and pole piece separated the maximum possible distance. With the aramture against the backstop the residual tension in the restoring spring is shown as the ordinate of point "a". It will be assumed that rated coil watts (1.2) is supplied to the relay. Point "a" must lie on or beneath the 1.2 watt curve, else the relay simply will not operate. The maximum pole gap and the rated static characteristic can then be used to determine the permissible residual tension in the armature restoring spring. As the relay operates and the armature approaches the nonmagnetic pole piece stop the point of operation moves along the 1.2 watt static characteristic from point "a" to point "b". When point "b" is reached the armature has completed its travel and the normally open contacts have closed. It will be assumed that in order for the armature to drop out the power input would have to be decreased to 0.2 watts. When the power input is decreased to 0.2 watts, point "c" is located. At point "c" the restoring force of the restoring spring exceeds the electromagnetic force of attraction of the pole for the armature and the armature begins to open. As the armature returns toward the backstop the point of operation moves from point "c" toward point "d" (with 0.2 watts supplied). When point "d" has been reached, the armature is against the backstop and the normally closed contacts have closed.

With 0.2 watts applied to the coil the pressure (or force) acting on the NC contacts at point "d" is the difference in the ordinates of "a" and "d". If the relay is deenergized the pressure on the NC contacts is the ordinate of point "a". With the relay energized (with 1.2 watts supplied) and the armature at point "b" the net force acting on the armature is the difference in the ordinates of points "c" and "b". If details of the contact-armature linkage were known, the force on the armature could be multiplied by the proper lever ratio to get the pressure on the NO contacts.

The following curves would have been more useful had force been plotted against pole gap for constant values of NI rather than W. The same static characteristics could then have been used for all relay coils (using proper NI characteristic whereas the curves shown are usable only for relay coils having a resistance of 30 ohms and 2150 turns.


Static Characteristics
of a Relay
Force in lbs. per sq. in. of Armature Surface
Pole gap in tenths of Inches
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0
Net Closing Force on Armature
Armature Travel
b
c
a
d
2 W
1.2 W operate
0.6 W
0.2 W release
Initial Force on Spring
Force on NC Contacts

SECTION III

ANALYSIS OF VIBRATION MACHINE

USE OF ELECTRO-DYNAMIC VIBRATORS FOR RELAY TESTING

Electro-dynamic shakers have wide varieties of applications, however, when considered in connection with relay testing only one function need to be considered. That function is to subject the relay to vibratory accelerations over a wide range of frequencies in order to excite the component parts of the relay at their natural resonant frequencies. This is for the purpose of determining the ability of the relay to withstand vibrations. To understand completely the use of electro-dynamic vibrators in relay testing, a knowledge of the characteristics of these machines is essential.

They consist of a high-density magnetic field which is established in a circular air gap by a d. c. field coil. A coil is suspended in the air gap and attached to the mechanical members necessary to transmit the forces generated in the shaker to the objects being shaken. Two sources of supply are necessary. A d. c. source is needed for the field coil and an alternating current source is needed to supply the armature coil. If vibrations which are variable in magnitude and frequency are desired (as in vibration-test for relays), then the a. c. source must be accordingly variable. The necessity for this may be easily seen when the equation governing the force produced on a coil in a magnetic field is examined. The basic equation for force on a current-carrying-conductor in a magnetic field is:

(1) $f = B\ell I$ joules per inch

or, converting units so the force will be expressed in pounds, and the conductor as a coil:

(1a) $f = 8.885 \times 10^{-8} B\ell NI$

$f =$ force in pounds

$B =$ flux density, lines per sq. inch

$\ell =$ length of armature turn

$N =$ Number of armature turns

$I =$ coil current, amperes

Assuming constant and uniform magnetic field the force produced by a particular vibrator may be expressed by:

(1b) $f = kI$

since ℓ and N are ordinarily not variable. This equation illustrates the ease with which the force produced by an electro-dynamic shaker may be measured in terms of the armature coil current.

The validity of the assumption made in order to simplify (1a) to (1b) should be examined. The first assumption, that of a constant and uniform magnetic field, is reasonably valid. Fringing effects and distortion due to the current flowing in the armature all tend to disturb the uniformity of the magnetic field. The second assumption, that of a constant number of turns on the armature, is true. However, it should be noted that in order to produce vibratory accelerations the armature must be mechanically displaced in such a manner as to produce the desired accelerations. This results in a varying number of armature turns which are in the field flux at different times, thus, the effective number of turns may vary.

Vibration tests on relays are usually conducted by subjecting the relay to a simple harmonic motion. The amplitude of the displacement is usually held constant in the first part of the test and the frequency increased until a specified value of acceleration is reached. This value of acceleration is then held constant and frequency is increased over a specified range. The latter step is to test for natural resonant frequencies.

If conventional alternating current of sin wave form is applied to the shaker armature, ($i = I_{max} \sin \omega t + \lambda$) the desired simple harmonic motion will be produced. The phase relationship between the armature voltage and current will be determined by two factors: (1) the impedance of the armature circuit, and (2) the nature of the mechanical load. The first of these depends upon design and frequency. The designer fixes the inductance and resistance of the armature coil. The inductive reactance and hysteresis and eddy-current losses increase with increased frequency. The effect of the mechanical load requires some explanation.

The power absorbed in a mechanical system may be determined from the time-rate at which work is performed. The equation for work is:

$$(\text{force})\ (\text{velocity})\ \cos \theta = \text{power}$$

In the case of electrodynamic shakers, the force and velocity are sinusoidal and colinear, thus they may be easily represented as two rotating vectors of constant magnitude and displaced in time-phase by the angle θ. This angle depends on the characteristics of the mechanical load. When the load is vibrated at a natural resonant frequencies $\cos \theta$ is equal to unity. At frequencies other than that required for mechanical resonance, θ may become very large. The relationships between the various quantities of an electro-dynamic shaker may be derived as follows:

Assume a current $i = I_m \sin (\omega t + \lambda)$ is flowing in the armature coil and from this establish the nature and relationship of the resultant forces, displacement, velocity and acceleration. As previously stated the current flow depends upon the impedance of the armature coil and the nature of the mechanical load. The current flow which results from armature impedance alone may be easily determined. The current flow resulting from the mechanical load must be determined from the nature of the load which consists of mass (armature mass plus mass of test object), a spring (the restoring force on the armature as well as spring elements in the test object), and friction.

If $i = I_m \sin(\omega t + \lambda)$ is substituted in the force equation (1b) then the force becomes a similar sinusoidually varying quantity

(1c) $f = kI_m \sin(\omega t + \lambda)$

Considering only the friction, mass, and effect of the armature restoring spring, the following equation may be applied to the mechanical system.

(2) $f = ma + k_1 x + k_2 {}^{dx}/_{dt}$

substituting (1c) $kI_m \sin(\omega t + \lambda) = ma \quad k_1 x + k_2 {}^{dx}/_{dt}$

When:

$f =$ applied force

$m =$ mass

$a =$ acceleration

$k_1 =$ spring constant of the restoring spring

$x =$ displacement

$k_2 =$ coefficient of friction

For the present purpose the solution of this equation may be satisfactorily accomplished by accepting the solution of the analogous electrical circuit equation*. This equation is:

(2a) $$E_m \sin(\omega t + \lambda) = L\frac{di}{dt} + \frac{q}{C} + Ri$$

and the steady-state term of the solution of this equation for, i, is:

* Analogies used are shown on the final page.

(2b) $$i_s = \frac{E_m}{Z} \sin(\omega t + \lambda - \theta)$$

Where:

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$\theta = \tan^{-1}\left[\frac{\left(\omega L - \frac{1}{\omega C}\right)}{R}\right]$$

Upon converting the solution of the analogous equation into terms of the original equation the following is obtained:

(3a) $$v_s = \frac{k I_m}{\mathfrak{Z}} \sin(\omega t + \lambda - \theta)$$

Where:

$$\mathfrak{Z} = k_2^2 + \left(\omega m - \frac{k_1}{\omega}\right)^2$$

$$\theta = \tan^{-1}\left[\frac{\left(\omega m - \frac{k_1}{\omega}\right)}{k_2}\right]$$

By differentiating the equation for velocity the acceleration equation may be obtained:

(3b) $$a = \frac{dv_s}{dt} = \frac{k \omega I_m}{\mathfrak{Z}} \cos(\omega t + \lambda - \theta)$$

and by integrating the velocity equation the displacement equation may be obtained:

$$x = \int v_s \, dt = \frac{k I_m}{\mathfrak{Z}} \int \sin(\omega t + \lambda - \theta) \, dt$$

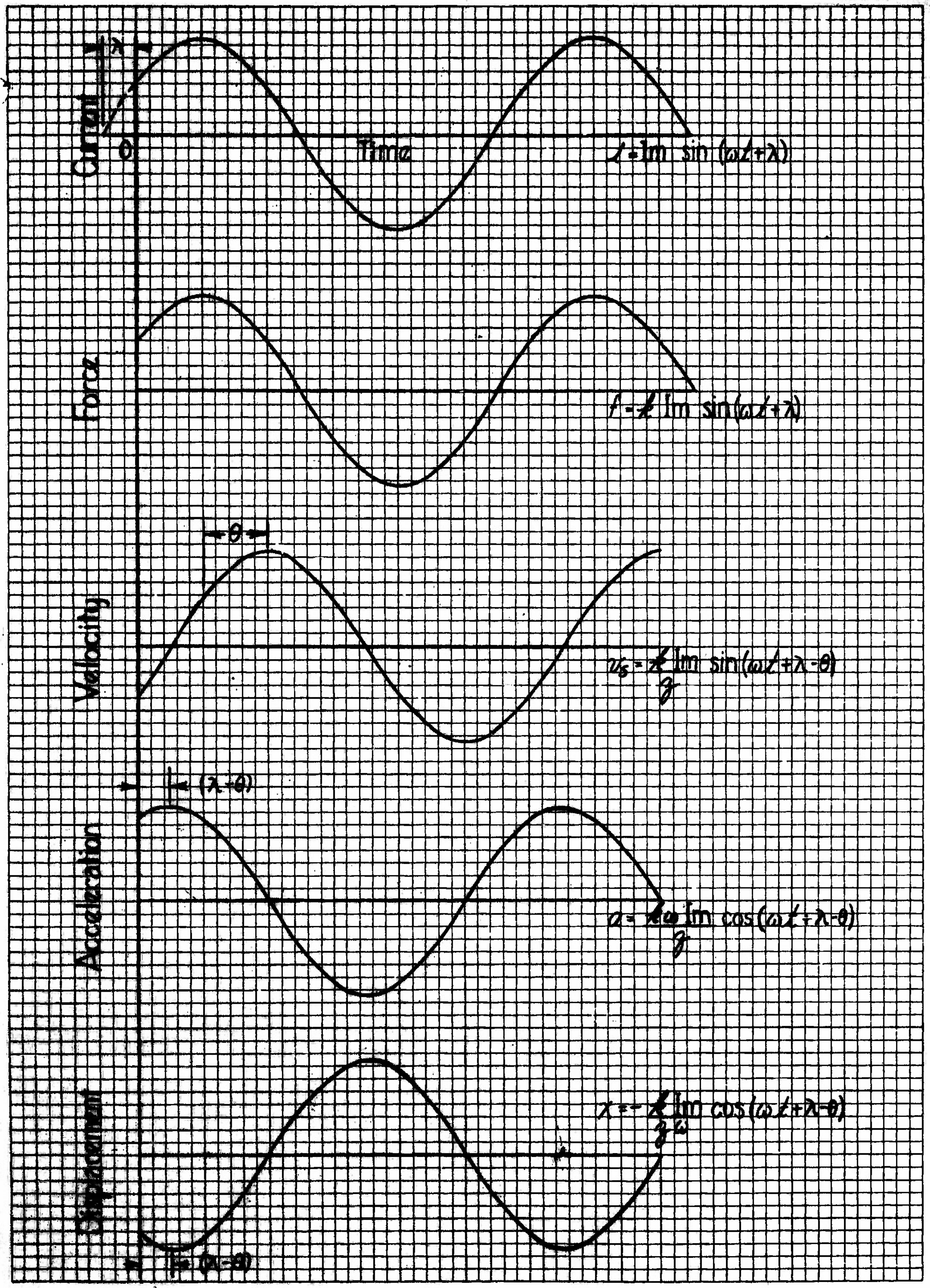
(3c) $$x = -\frac{k I_m}{\mathfrak{Z} \omega} \cos(\omega t + \lambda - \theta) + C_1$$

Due to the fact that only the stedy-state condition is being considered no boundry conditions exist to permit a rigorous determination of the constant of integration in the preceding equation. However it may be justifiably assumed to be zero when the effect of a constant in such an equation as (3c) is considered. The effect would be to shift the axis about which the variation represented in the first term of the equation takes place. This means that when referred to the same axis as that for the velocity and acceleration the variation in displacement is unsymmetrical. If C_1 were to have a positive value the positive peak value would be greater than the negative peakvalue and vice-versa. Since such non-symmetry does not exist in the actual displacement the value of C_1 must be zero.

The curves of Figure 1 illustrate the relationships established by the preceding equation.

Equation (3a) wherein the angle θ appears, illustrates how θ is dependent upon frequency, friction, mass, and spring constants. At a mechanical resonant frequency the value of z becomes equal to k_2 which is its minimum value. When $z = k_2$, $\theta = 0°$ and a unity power factor mechanical system exists.

The variations in θ and z with frequency are reflected in the armature coil circuit, which results in the need of an armature power supply which will be capable of supplying a relatively large amount of power at poor power factors.


Current
λ
0
Time
$i = I_m \sin(\omega t + \lambda)$
Force
$f = k I_m \sin(\omega t + \lambda)$
Velocity
θ
$v_s = \frac{k I_m}{z} \sin(\omega t + \lambda - \theta)$
Acceleration
$(\lambda - \theta)$
$a = \frac{k\omega I_m}{z} \cos(\omega t + \lambda - \theta)$
Displacement
$x = -\frac{k I_m}{z\omega} \cos(\omega t + \lambda - \theta)$
$(\lambda - \theta)$

ANALOGIES USED

Electrical Quantity		Mechanical Quantity
voltage	analagous to	force
current	"	velocity
resistance	"	friction
inductance	"	mass
capacitance	"	^{1}/spring constant

SECTION IV

STANDARD RELAYS

EXAMPLES OF ADOPTED STOCK RELAYS

On the following pages two examples of Military Standards of adopted stock relays, similar to the one in the December Report, have been developed. It is evident upon examination of the examples that the information given is inadequate for complete specification. Using the only information available, the manufacturers' catalogs, it is impossible to completely specify any of their relays. The information in the catalogs was written primarily for sales purposes, and therefore no attempt has been made to supply sufficient technical data for specification purposes.

The first example, the Clare type K relay, would be easier to fit into a uniform scheme of classification than the relay used as an example in the December Report. For example, the Clare type K uses a standard octal plug-in type header. Also, the terminal connections used on this relay could apparently be easily adapted to the proposed scheme for standards. The voltage ratings of the different coils normally supplied with the relay were in agreement with proposed standard coil voltage ratings, except for the coil voltage of 60 volts. However, should it be found desirable to have relays as stock items whose coils were rated at 60 volts, this voltage rating could easily be added to the proposed standard coil voltage. The major difficulty in adopting this relay as a stock item would probably be in getting the dimensions to fit the proposed preferred numbering system.

The second example, Allied Relay No. SKH, has rated voltages for standard coils that conform exactly with the proposed standard voltage ratings. The terminal connections, however, do not follow the proposed scheme for standard terminal connections. The mounting plan uses triangular spaced studs, but, while superior to the mounting plan used by the example in the December Report, the actual spacing of studs would probably not fit a preferred system of mounting dimensions. The relay dimensions would prpbably be affected in a manner to the mounting dimensions discussed above. For solder type relay terminals on sealed relays some method should be devised for numbering the terminals. It appears that this relay would be fairly easy to fit into a standard shceme of relay classisfication.

The following pages do not purport to be accepted Military Standards, but are included for illustrative purposes only.

NOMINAL RATING

DC only
Rated Coil Voltages - 6, 12, 24 or 60 volts
Coil Resistance - See page 2
Rated Ampere Turns - See page 2
Contacts Rated at 2 Amperes, 150 Watts Non-Inductive AD Load

For Contact Arrangement - See page 2
Octal Plug-In
Cover Is Sealed Steel Can
Continuous Duty
Armature Type Movement
On-Off Characteristic Operation

TEST	PHYSICAL REQUIREMENTS	LIMITS
Visual and Mechanical		
Height	2 11/32 inches	----
Diameter	1 21/32 inches - See page 3	----
Terminals	Octal Plug-In	----
Contact Material	Palladium	----
Terminal Arrangement and Connections	See page 3	----

TEST	PERFORMANCE REQUIREMENTS	LIMITS
Sealing	Hermetically Sealed	----
Operate Time	See page 2	----
Release Time	See page 2	----

ADDITIONAL REQUIREMENTS

1. For inspection tests, sampling and inspection shall be in accordance with the Test Code to be developed.
2. Reference specifications and standards shall be of the issue in effect on date of invitation for bids.
3. Qualification approval required

PROPOSED SPECIFICATION OF ADOPTED STOCK RELAYS
(Example - Clare Type K)

PART NO. MS

Custodian: Navy-Bureau of Ships	MILITARY STANDARD	MS
Procurement Specification	Miniature Relay - Vibration Resistant Clare Type K	Sheet 1 of 3

COIL DATA FOR STANDARD COILS AND CONTACT ASSEMBLIES

Coil Number	Assembly Number	Resistance ohms	Number of Turns	Wire Size (AWG)	Rated Volts	Wire Per Figure
W6-1020	SK5001	300	4200	38	24	A
W6-1021	SK5002	300	4200	38	24	B
W6-1021	SK5003	300	4200	38	24	C
W6-1021	SK5004	300	4200	38	24	D
W6-1021	SK5005	300	4200	38	24	E
W6-1023	SK6006	120	3000	35	12	B
W6-1021	SK5007	300	4200	38	24	F
W6-1023	SK5008	120	3000	35	12	F
W6-1017	SK5009	30	1600	32	6	B
W6-1022	SK5011	700	7300	39	40	G
W6-1017	SK5012	30	1600	32	6	A
W6-1023	SK5013	120	3000	35	12	A
W6-1014	SK5014	1300	9800	40	60	A
W6-1021	SK5015	300	4200	38	24	J
W6-1021	SK5016	300	4200	38	24	K
W6-1021	SK5017	300	4200	38	24	J
W6-1021	SK5018	300	4200	38	24	L
W6-1021	SK5027	300	4200	38	24	R
W6-1027	SK5028	6500	20000	44	60	A
W6-1014	SK5029	1300	9800	40	60	P
W6-1014	SK5030	1300	9800	40	60	B
W6-1027	SK5034	6500	20000	44	60	B

STANDARD ADJUSTMENT

Spring Assembly	Ampere-Turns Required
1 Form C	180
2 Form C	230
3 Form C	270
4 Form C	320

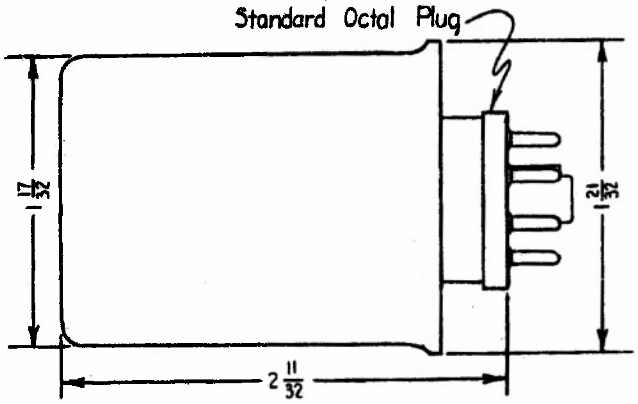
Operate and Release Times for Standard Coils With Standard Adjustment

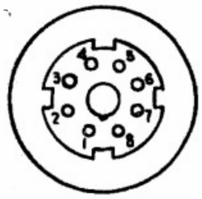
Applied Voltage	Contact Assembly	Seconds Operate Time	Seconds Release Time
12	1 Form C	.0045	.0018
12	2 Form C	.0085	.0010
24	1 Form C	.0040	.0020
24	2 Form C	.0055	.0015

PART NO. MS

Custodian: Navy-Bureau of Ships	MILITARY STANDARD	MS
Procurement Specification	Miniature Relay - Vibration Resistant Clare Type K	Sheet 2 of 3

DIMENSIONAL DRAWING AND MOUNTING



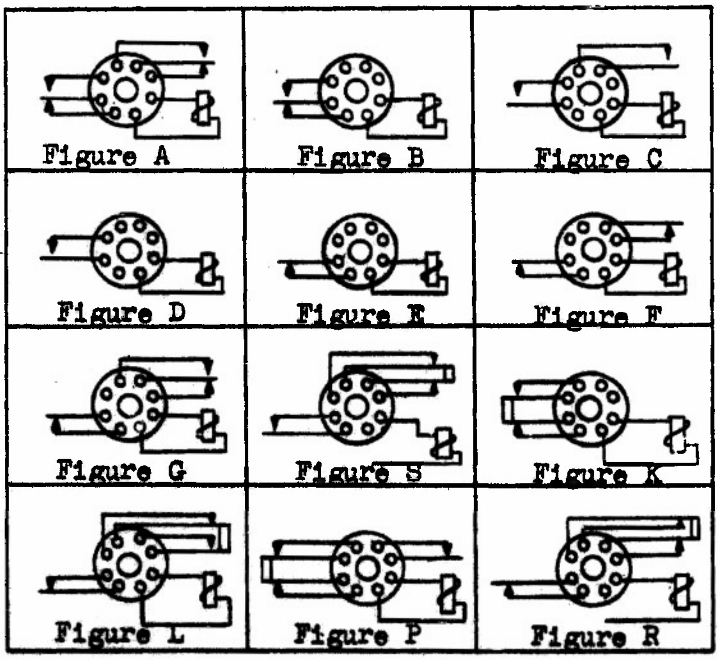


Standard Plug
Numbering Systems

NOTES: 1. All dimension in inches.
2. No tolerances given.

BASE WIRING - BOTTOM VIEW

Note: These are terminal connections and contact arrangements for relays listed on page 2.



		PART NO.MS
Custodian: Navy-Bureau of Ships	**MILITARY STANDARD**	**MS**
Procurement Specification	Miniature Relay - Vibration Resistant Clare Type K	Sheet 3 of 3

NOMINAL RATING

DC only
Rated Coil Voltages — See page 2
Rated Coil Currents — See page 2
Coil Resistance — See page 2
Rated Coil Power is 2.75 watts for 20^{o} ambient and for continuous operation.
Contacts rated at 1.0 ampere at 24 volts DC or 115 volts AC non-inductive load.
Contact arrangement is any combination through 4PDT.

Cover - Sealed in Steel Can
Terminals are solder type.
Mounted by three, triangular spaced #6-32 studs
Hermetically sealed
Continuous Operation
Aramture type movement
On-Off operation

TEST	PHYSICAL REQUIREMENTS	LIMITS
Dimensions:		
Height is	- 2 1/2 inches	----
Cross-section	- 1 13/32 X 1 19/32 inches	----
Terminals	Solder type	----
Terminal height	7/16 inch	----
Terminal Arrangement and Connections	See page 3	----

TEST	PERFORMANCE REQUIREMENTS	LIMITS
Sealing	Hermetically sealed	----
Minimum Operate Current	76.2% of Rated Current	----
Contact Capacitance	4 to 5 f	----

ADDITIONAL REQUIREMENTS

1. For inspection tests, sampling and inspection shall be in accordance with the Test Code to be developed.
2. Reference specifications and standards shall be of the issue in effect on date of invitation for bids.
3. Qualification approval required.

PROPOSED SPECIFICATION OF ADOPTED STOCK RELAYS
~~(Example - Clare Type K)~~

PART NO.MS

Custodian: Navy: Bureau of Ships	MILITARY STANDARD	MS
Procurement Specification	RELAY - GENERAL PURPOSE (Allied No. SKH)	Sheet 1 of 3

COIL INFORMATION

Standard Coils used for any contact combination up to 4PDT when power consumption and sensitivity are not important.

D.C. Volts	6	12	24	48	110
Wire Size	31	34	37	40	42
Resistance	28	111	425	1387	4500
Amperes	.214	.108	.057	.0346	.0244

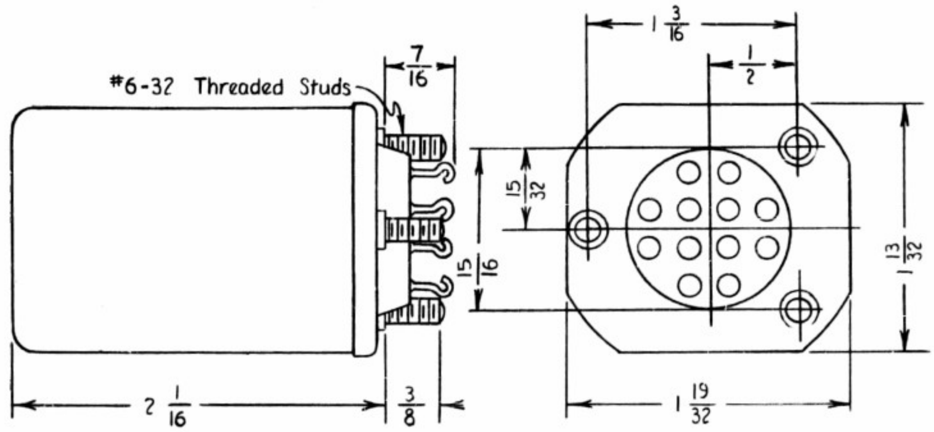
Coils used to obtain maximum performance where ambient temperature and vibration are not factors.

Rated Coil Voltage (Volts)				Wire Size	Coil Resis. in ohms.	Rated Coil Current (Amperes)			
Contact Forms						Contact Forms			
O-C	C-C	CC-C	CC-CC			O-C	C-C	CC-C	CC-CC
.145	.204	.256	.301	20	.12	1.21	1.70	2.13	2.51
.234	.330	.413	.487	22	.32	.732	1.03	1.29	1.52
.383	.539	.675	.793	24	.84	.456	.042	.803	.944
.612	.862	1.08	1.27	26	2.2	.278	.392	.490	.576
1.01	1.4	1.78	2.09	28	5.8	.174	.245	.306	.360
1.21	1.71	2.12	2.50	28	7.75	.156	.220	.274	.323
1.61	2.27	2.82	3.33	30	15.0	.107	.151	.188	.222
1.92	2.71	3.38	3.98	30	20.5	.094	.132	.165	.194
2.58	3.64	4.56	5.34	32	39.0	066	.093	.117	.137
2.90	4.08	5.10	6.0	32	43.2	.067	.094	.118	.139
4.17	5.97	7.35	8.64	34	102.0	.041	.057	.072	.084
4.89	6.89	8.61	10.13	34	111.	.044	.062	.077	.091
6.58	9.26	11.6	13.6	36	260.	.025	.035	.044	.052
7.48	10.56	13.2	15.5	36	257.	.029	.041	.051	.060
10.54	14.8	18.5	21.8	38	680.	.015	.021	.027	.030
12.0	16.9	21.2	24.9	38	639.	.018	.026	.033	.038
17.3	24.5	30.6	36.1	40	1750.	.009	.014	.017	.020
17.6	24.8	31.1	36.6	40	1387.	.012	.017	.022	.026
27.5	38.3	48.1	56.3	42	4500.	.006	.008	.010	.012
Rated Ampere Turns						139	196	245	288

PART NO. MS

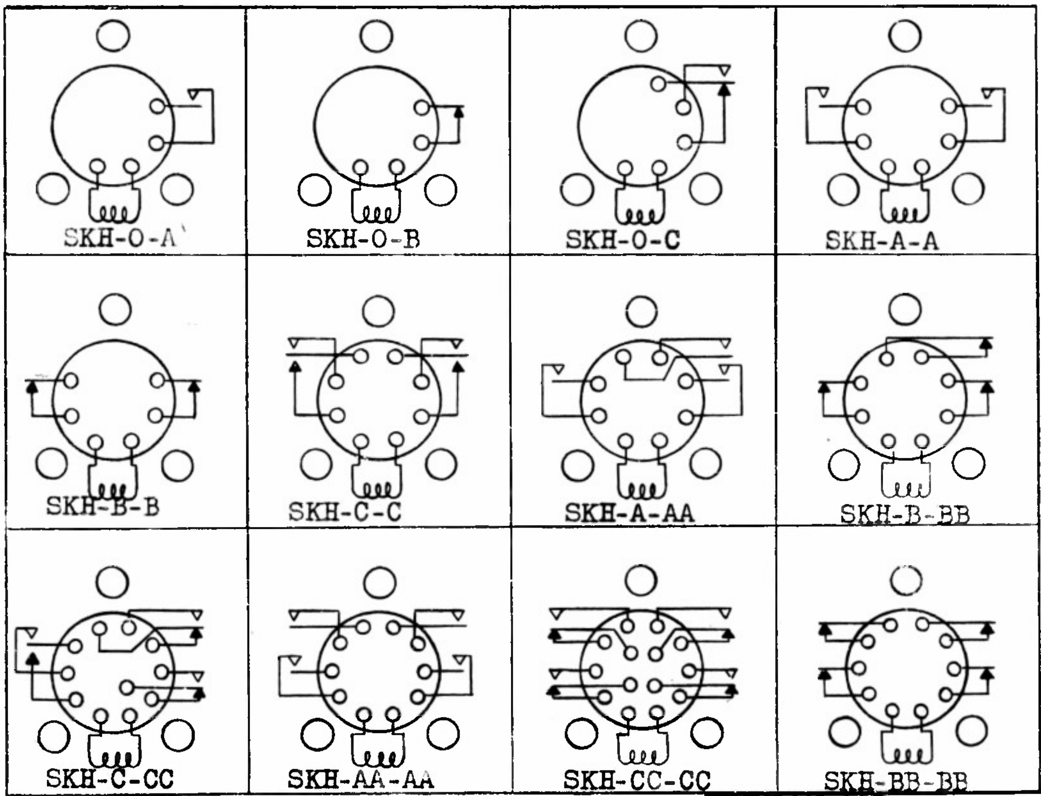
Custodian: Navy-Bureau of Ships	MILITARY STANDARD	MS
Procurement Specification	RELAY - GENERAL PURPOSE (Allied No. SKH)	Sheet 2 of 3

DIMENSIONAL DRAWING AND MOUNTING



Note: 1. All dimensions given in inches.
2. No Tolerances given

BASE WIRING - BOTTOM VIEW



PART NO. MS

Custodian: Navy-Bureau of Ships	**MILITARY STANDARD**	**MS**
Procurement Specifications	RELAY - GENERAL PURPOSE (Allied No. SKH)	Sheet 3 of 3

SECTION V

LETTERS ABOUT REPRINT

WHAT MAKES FOR "RELIABILITY IN RELAYS?

An article "What Makes for 'Reliability' in Relays?" by Charles F. Cameron was published by Electrical Manufacturing, October, 1952.

A reprint of this article was published as Bulletin Number 2, Volume 19 of the Oklahoma Engineering Experiment Station of the Oklahoma Agricultural and Mechanical College. This reprint was enclosed as a part of the December report.

Copies of the reprint were mailed to personnel of the different relay manufacturers and other persons interested in relays. Several letters have been received relative to the article. Quotations from some of these letters are included herewith because of the particular ideas expressed.

The Manager of Specification and Standards Department of Collins Radio Company, Cedar Rapids, Iowa, states: "We have read with considerable interest your article on Reliability of Relays in the Electrical Manufacturing magazine for October 1952. As a major user of specialty relays, we too have been confronted with the general problem of standardization. Our relays are used in many types of equipment such as the AN/ARC-27 Standard UHF Military Communications Equipment, AN/GRC-19 Signal Corps Communications Equipment, AN/ARN-14 Airborne Omni-Range Navigation Equipment, and many others.

Our general equipment specification dictates rather severe environmental conditions, but at the same time we are almost invariably pressed for unusually difficult size requirements. We find that the absence of standards of any kind makes it extremely difficult to develop alternate sources of supply.

We may be able to be of some assistance in a general standardization program from the standpoint of providing you with copies of procurement specifications or copies of component test reports. We would appreciate being kept informed on general standardization activities in this field since we believe that the equipment manufacturer should play an important part in the preparation of component standards."

The Supt. of Control and Guidance Division, Aeronautical Electronic & Electrical Laboratory, E. W. Schlieben, U. S. Naval Air Development Center, Johnsville, Pennsylvania writes," We have read with considerable interest your comments on "What Makes for Reliability in Relays" as they appeared in the October issue of Electrical Manufacturing. Noting particularly that your work in relays is being sponsored by the Department of the Navy, we would accept your invitations to comment on some of your suggestions.

Your observe that "more often than not, relays are considered to be auxiliary devices which are buried deep in a complete equipment. They are usually added at the last of the design to perform a given function regardless of anything else that may happen to the equipment". May we suggest that there is now a rather large and growing class of users to whom the relay is not an auxiliary device added as an afterthought, but rather is one of the fundamental units of the system. The truth of this statement is usually evident to anyone who has had the opportunity to examine the electrical system of some Naval Aircraft. Automatic fuel transfer systems, some types of automatic pilots and various other special automatic control systems abound with relays. On Navy drone aircraft, as many as 60 relays have been packaged in a single unit to perform the function of a signal distributor center. In such cases, the problem of relay reliability has added significance.

Some manufacturers now package special relay circuits consisting of 2 or 3 or 4 small relays sealed in one container and designed to perform a specific job. This results in a better form factor than can be achieved by separate sealed relays. This raises the question as to the desirability of designing systems using sealed relays versus designing systems with open relays and mounting all in pressurized gasket sealed containers.

In many relay applications contacts are required to handle load having high inrush currents but low operating currents. In aircraft systems, this is true of such loads as flashing lights, intermittent duty D.C. motors and some solenoid operated valves. Because of the effects of armature and contact "bounce" during closing, many relay contacts arc severely during closing. This has an undesirable effect on reliability. Smaller relays, having less current handling capacity but less susceptable to armature and contact "bounce", are better. Can anything be established concerning contact bounce on a standardization program? You do not discuss this. Our work would seem to indicate that this subject of armature and contact bounce is deserving of much more attention than it has received in the past A rather detailed mathematical treatment of this subject is to be found in the Bell System Technical Journal for the first quarter 1952.

You have discussed contact pressure and contact materials as important factors. Since the important function of any realy is to make a contact, can contact resistance be taken as an index of contact pressure, power and reliability? There is some evidence to indicate that it can. Perhaps contact resistance maximums could be established for various materials and designs.

Because of the nature of some of our work we are interested in this subject of "What Makes for Reliability in Relays". If you or your associates should reach any conclusions as a result of your thinking on this subject, we would appreciate learning of your findings. Perhaps you would advise us of the Navy Contract No. under which you carry on this work. With this information, The Naval Air Development Center can obtain copies of reports on your work from the Bureau of Ships and undoubtedly benefit from them."

Eleven typewritten pages and one drawing were received from J. A. Csepely, Materials and Standards, Air Arm Division, Westinghouse Electric Corporation, Friendship International Airport, Baltimore, Maryland. The subject was comments and suggestions regarding the article.

Mr. A. C. Johnson, Relay Division, The Adams & Westlake Company, Elkhart, Indiana, says, "I have read with great interest the reprint of your paper "What Makes for Reliability in Relays". and believe that you have covered the subject very well from a mechanical relay standpoint. However, as one who is employed in the mercury, plunger-type relay industry, I believe that more stress and consideration should be placed on the abilities of the mercury relays.

In evaluating a customer's application, we take into consideration all of the various factors that you have outlined plus the questioning as to whether the relay will be called upon to make or break the load or whether this action will occur on both cycles of the relay. We have found from experience that this is a highly desirable bit of information in that it protects against undue stress being placed on certain points of the design. As a word of information, all of our line of mercury, plunger-type relays are rated on a breaking current under an adverse duty cycle of approximately 44 times per minute. We also inquire as to the possible presence of surges in the circuit that may be handled by the relay, as this is very good information to have to prevent the failure of the equipment and prevent a tendency on the part of the designer to avoid relays due to a bad experience with them at some time or other which was absolutely beyond the control of the manufacturer.

I firmly believe that the investigation of surges would prevent some of the resistance on the part of designers to relays and I believe that this opinion fits into your theme of thorough investigation to insure reliability.

The mercury, plunger-type relay is of course a unique device and we do have a nomenclature that is more or less distinct and peculiar to the industry. We speak of pick-up and drop-away. By the former we mean the lowest point in the voltage range at which the relay satisfactorily fills the specification. The latter denotes the point at which the relay resumes its normal position. Also, we speak of the recycle period which in the case of time delay relays, has a distinct bearing on the application. By the term recycle, we mean the differential in time from the period at which the relay is deenerigized until it is again energized and normally this period of off time equals the time delay of the relay.

I note with interest that you have stated specifically that the nature of the load should be considered and I believe that this is a very definite point that should be brought out in conjunction with relay specifications. We consider the nature of the load as of prime importance. While we do have ratings established for inductive loads, we use as a rule of thumb measure, and I believe that most manufacturers will agree with this, that the inductive rating of the relay is approximately 40% of the non-inductive rating of the same device.

It is hearteningfor one to know that an individual such as yourself has taken such an express interest in relays and their correct application and at the risk of being arbitrary, I would like to point out once again that more emphasis should be placed on the desirability of using mercury, plunger-type relays. We, of course, believe that they are far superior to mechanical equipment, however, we do realize that they have their limitations in military applications where shock plays such an important part, but the experience and performance of the device has proven that for industrial use that none will out perform this type of equipment.

We, in the industry, realize, however, that we do have a very large selling job to do to overcome the objections that have been raised and the resistance that has been developed upon the basis of the performance of the original mercury switches which were of glass construction, but with the new developments incorporating stainless steel housings in place of the glass envelopes, we feel that the day will come when one can say, "we are now of age".

I wish to thank you very kindly for soliciting the writer's humble opinion on this subject and hope that you will find some article of value in my remarks."

The subject of thermal delay relays is injected into the general discussion by William H. Nickless. "We have read with interest your pamphlet entitled, "What Makes for Reliability in Relays". As manufacturers of thermal delay relays, we would apprecialte knowing whether you intend at some future date to report on these devices as you have done with magnetic type relays."

The Chief Engineer of Struthers-Dunn, Inc., C.A. Packard, suggests that the disadvantages of hermetic sealing of relays and he writes, "I thank you for your letter of Dec. 4, 1952 inclosing a reprint of an article entitled "What makes for Reliability in Relays?" I am very much interested in this important project of yours and I trust that you will keep me on your mailing list to receive further releases.

In future releases, particularly if they are to be read by the general public, I would suggest that along with the advantages of hermetic sealing, you mention the big disadvantage. Vapors from plasticizers and metallic vapors from contact arcing must be eliminated or the hermetic seal instead of increasing the life may decrease the life by a ratio of 100:1 or more. It is only safe to seal a relay that was built to be sealed. Relays such as our 8BXX6 illustrated in your article have been known to drop from 1,000,000 operation life to 300 when hermetically sealed."

A Marshall Plan exchange student wants the works, which he did not get, and his letter, "I am a Marshall Plan exchange student presently in this country for the primary purpose of studying American industry.

Prior to returning to my native Italy I am desirous of securing technical information for the calculation of relays.

I have had the opportunity to read your article in a technical magazine just about this subject. So I am asking you if you can send me in some form all matter necessary for the calculation of relays. This matter to deal with the calculation of cores, coils, the dimension of contacts for different currents, the pressure on the contacts and all Standard denominations of relays.

This information to cover of course, the large and small types of relays, industrial and telephone, relays for large, meduim and small currents, and over-load types, too.

I would appreciate anything you would say, to give the occasion to improve my knowledge.

Other individuals at the Westinghouse Electric Corporation, Friendship International Airport, Baltimore, Maryland, A.T. Hamill, Manager, Materials and Standards, Air Arm Division, Per George K. Borski write, "This letter is in reference to you letter of December 4th,1952, concerning your article "What Makes For 'Reliability' in Relays" which appeared in the October issue of "Electrical Manufacturing".

Our work here at Air Arm is entirely involved with Airborne equipment for the government. Our current problems with relays are in size, temperature range, and resistance to vibration and shock. We use almost entirely hermetically sealed relays. The ambient temperature range through which most of our relays operate is -65 to 125°C and in some cases even higher.

Our vibration requirements for several relays are far more severe than those called for in MIL-R-5757B. We have made vibration tests up to 500 cycles per second at 15 G on several types of relays. We have found, although contact flutter was encountered in nearly all cases, that the rotary action relays are more resistive to vibration than the conventional type.

We are also employing many thermal time delay relays in our equipment. We are having difficulty in reliability of thermal relays with time delays above 45 seconds.

We also require hermetically sealed relays small in size with contact ratings between 15 and 20 amps.

These are a few of the many problems we are encountering with relays. We wish you success in your program of standardizing relays, and please feel free to call upon us for any aid in this mutual problem."

Norman E. Hyde, British Liaison Officer, British Joint Services Mission, ASESA, Fort Monmouth, N.J., comments on the article, "In answer to your letter of 4 December I must apologize for not being in a position to devote the required amount of time to digest the above article and comment accordingly in the way that I would like, but in haste I will raise a few suggestions for your consideration if you think it worthwhile.

2. In the order of your paper the first thing to strike me was the definition of a relay. I think either a DC rating should be enclosed in the definition or else a table of conversions supplied for AC to DC loads. I know this in turn will raise a complex question of what is a non-inductive DC load but it must be faced.

3. The second point is that I feel that bounce has not been sufficiently dealt with. This is especially so in the case of high speed relays where the parameters of bounce become very important.

4. On the last page there are two very minor points. Under the paragraph heading "Insulation" have you defined high voltage? In UK we consider high voltage when associated with relays as anything over 100 Volts DC or AC RMS. The last little thing is your optimistic statement undoubtly put in to make

relay manufactures happy, is the last sentance in which you refer to a natural out growth of standards. I have always found that standardization has to be forced on the designer and engineer and measures taken by the services to prevent manufactures from introducing any old relay to these engineers."

The Manager of the Relay Division, R.S. Warren, of The Adams & Westlake Company, Elkhart, Indiana discusses reliability as applied to the mercury, plunger-type relay."We appreciate the opportunity you have given us to review your paper and offer such suggestions as we may have, particularly where the conditions are applicable to our plunger-type, mercury relays. We, here at the Adams & Westlake Company, believe there is a tremendous void in the atmosphere surrounding the word "Reliability", as far as it concerns our particular type of relay. We believe that without a true sense of just what is reliable in relays, an extremely troublesome and possibly dangerous condition may be allowed to develop in certain applications.

In your article, you have covered electro-mechanical relays and have outlined many points to be considered in setting up standards which will assist in determining the "reliability" of relays. We believe you are correct in stating that such standards should not restrict, or for that matter point the way for the design pattern, but should consider the conditions under which the relay must operate.

Mercury, plunger-type, relays have many points in common with electro-mechanical relays, however, in many ways they cannot compete with the mechanical relay. Conversely, there are many ways wherein the mercury, plunger-type, relay is far superior to any known mechanical relay. Mercury relays cannot be used in aircraft, however, they can be used at any altitude and in any humidity including being submerged in water and the only restriction as far as temperature is the freezing point of mercury. They cannot be used under severe cases of shock in both energized and de-energized conditions, however, they have been used successfully where shock and vibration are prevalent when the contact is closed.

The distinction between a relay and a contactor is of no particular importance to us, inasmuch as we consider our device a relay through all its ranges of capacity up to and including 50 amperes on 115 volts, 60 cycles, non-reactive.

As far as relay classification is concerned, we have simplified ours to the extent that we have a sensitive relay, a time delay relay, and a load relay. I do not believe there is a great variety of classifications of the plunger-type, mercury relay as can be found in the mechanical type of relay.

In the section headed, "Relay Selection", we believe you have covered the essentials for determining the proper relay and the items set forth are the same as we require for our mercury relays. We suspect that when the specifications covering "voltage" are given that the values for the "current" are not required. In certain cases where a current coil is required, it might be possible that the voltage drop allowable will be limited and in that instance, it might be necessary to have voltage and current given in the specifications. With the question of the type of contacts, we are at a disadvantage in that our relays are essentially single pole, single throw and contact grouping in a single relay is not practical. We do in many instances, however, group relays in units and by that manner obtain single pole, double throw, double pole, single throw or double pole, double throw, etc.

In considering mercury, plunger-type relays, it should be remembered, of course, that humidity, atmospheric pressures, and dust, dirt, water, chemical fumes or explosive atmospheres have no affect on the contacts of the relay.

We thank you very kindly for giving us the opportunity to comment on your paper and to set forth a few points which are pertinent to our particular product and which are distinguished from those points which are vital to the electro-mechanical relay.

Additional copies are requested by Richard S. Kurtz, Sales Engineer of Heinemann Electric Company, Trenton 2, New Jersey. "Thank you very much for your reprint entitled "What Makes For 'Reliability' in Relays".

Our Engineering Department particularly, has shown a great deal of interest in this article. We would appreciate your forwarding us six additional copies if available.

The Chief Engineer, W.C. Broekhuysen, of G-V Controls, Inc., East Orange, N. J. writes, "We have read with great interest your article on Reliability in Relays, which discusses the factors entering into Standardization of Relay Specifications.

Our company is engaged in the manufacture of one specific type of relay, namely Thermal relays. Though these are used in the first place as Time-Delay relays, they find application also as critical-voltage of critical-current relays, regulators, frequency discriminators, for overload protection, etc. All our relays are at present hermetically sealed and all are of the slow-make-and-break type as contrasted with snap-action or toggle-action relays. One of our latest bulletins is enclosed for your information.

In the past we have run into some difficulties with specifications, which were obviously written for magnetic relays, being applied to thermal relays without taking into account the different characteristics of the latter. We are therefore vitally concerned with any standardization of specifications. Particularly when subjected to vibration, the action of a gradually closing contact is fundamentally different from that of the normally fast-closing contacts of a magnetic relay.

Standardization of base connections for plug-in type relays concerns us too. The miniature 7-pin base or the octal base forms an integral part of our relay structure which is supported directly on the pins. In the octal size we were able to adhere to the connection diagram of the Thomas A. Edison Inc. relay which preceded ours, even though they are based on different principles, without any sacrifice in simplicity or efficiency of the design. In the 7-pin miniature size we were the pioneers and adhered to the same diagram. While there is some flexibility in the design, we might be unable to conform to an arbitrary standardization."

The sentence, "While there is some flexibility in the design, we might be unable to conform to an arbitrary standardization, " is an important statement. Our desire is to formulate a series of Standards and Test Code with the corresponding Specifications that will be commercially acceptable and still leave room for continued improvement in design.

Jack W. Reed, Field Inspection Coordinator of Bendix Aviation Corporation brings up some interesting topics. "On a recent visit to Allied Control Company, inc., New York, we were informed that the National Association of Relay Manufactures were in the process of rewriting and adding to the existing specifications for relays. As Field Inspection Coordinator for the Kansas City Division of Bendix Aviation Corporation, I am very much interested in any attempt to assure better correlation between vendor-customer inspection methods and equipment.

Field Inspection work in our division is relatively new, but we have sufficient evidence to substantiate the need for more precise specifications. The existing specifications, either Jan or Mil. Specifications, fail to give specific information on the desired accuracy of test equipment or type of equipment. Due to the type of work Bendix does, we find it necessary to design most relay products and, therefore, must also give test procedures and qualifications for relays. In this system, we have found that our engineering ideas vary with the manufacturer's ideas; and no existing specification covers the matter entirely.

Recently we have had disagreements with relay manufacturers is regard to hi-potting relays. Our specification is that the relays meet 750 volts RMS without breakdown. It would seem that this specification is clear; but due to the difference in commercial hi-potting equipment, the results were different in all vendor samples. Each vendor was using an indicating source of different value, ranging from .5 ma. per 750 volts to 35 ma. per 750 volts. It can be seen that the vendor using an indicating source of .5 ma. to indicate a breakdown will have to manufacture a much better relay than those using a 35 ma. indicating source. It was also found that if Bendix used an indicating source of .5 ma., we would reject a large percentage of relays manufactured by the vendor using a 35 ma. indicator on their hi-pot.

As an end result, our Engineering Department put out the following statement:

"In testing for hi-pot breakdown, anything short of a complete total breakdown should not be construed as a hi-pot failure. If a current indicator is used, it should not indicate until the current is much greater than the value which would be expected through the minimum allowable leakage resistance."

With this as our basis, we have set up a specification agreeable to all vendors, that the indicating source should be at least 5 ma. per 750 volts RMS on this relay. By using an indicating source of 5 ma. per 750 volts RMS, we are assured that any breakdown will be absolute and not the effect of corona discharge or leakage resistance.

Other points of disagreement have been measurement of contact pressure, closing time, contact resistance and contact bounce. Of these, we have had the most trouble with closing time or operating point of a relay. An example is using a relay consisting of Form "C" contacts. Some vendors consider the operating time of the relay to be the opening of normally closed contacts. Other vendors consider it to be at the time the normally open contacts close. It is true that the difference in this case is small, but if near the maximum tolerance, the difference in technique would mean acceptance or rejection of the relay.

Bendix is now set up to cope with these discrepancies between customer and vendor, but it is our opinion that more continuity in specifications could only mean better efficiency of Quality Control and reduce the cost of field inspection work. We are very anxious to work with you in any way we can to expedite and furnish information regarding the rewriting of relay specifications. We would appreciate any comments you have on the work already achieved toward the new specifications and would like to be placed on the mailing list for forthcoming information along this line."

There were other letters received but no new ideas were discussed.

SECTION VI

DIGEST OF PAPERS

MINIATURIZATION-MINIMIZING OF ELECTRONIC EQUIPMENT

With electronic equipment the compactness feature is becoming more and more important. With this added desirability there must be maintained the high efficiency and reliability which goes to make for a successful product. Through the endeavor of miniaturization much has been accomplished; not only have smaller parts been developed, but almost invariably better products have resulted.

The objectives of miniaturization in electronic equipment are as follows:

1. Reduction in size
2. Reduction in weight
3. Reduction in complexity
4. Faster means of testing with reduced maintenance
5. Increased reliability
6. Standardization

Vacuum Tubes. The decrease in size of vacuum tubes has been accompanied with an increase in transconductance by as much as a factor of four for equivalent plate voltage and cathode power. In some cases the tube weight has dropped by a factor of nine and the volume has been cut twice as fast. In addition to structural changes, vacuum tube ruggedness has been improved through miniaturization, since a reduction in size makes possible the withstanding of greater vibrations and centrifugal forces.

Resistors. Resistors have been increased in stability and decreased in both volume and weight. For example, a two watt resistor has been cut to less than 50 per cent of its former weight, while the volume has been reduced to approximately 25 per cent of its former size.

Improved economy in resistor production has been acquired through additional resistor ratings below ½ watt. The smaller size resistors can in many cases be utilized where formerly the $\frac{1}{2}$ watt size was used.

Other. The demand for improved inductors in vhf communication has motivated research leading to: (1) Metallized glass inductors; (2) new developments with toroidal coils; (3) construction of iron-enclosed inductors occupying less than $\frac{1}{4}$ cubic inch; and (4) smaller inductors for lower frequencies.

Audio transformers and instruments have been reduced in size through the use of modified nickel irons of high induction permeability and silicone insulations.

Further materials and processes used in miniaturization are: (1) High-dielectric ceramics; (2) high-strength porcelains; low-loss plastics; (3) low-loss steatites; (4) printed and photo-etched circuits; and (5) new and improved coatings.

Miniaturization relies upon several principles which must be incorporated in turning out a finished product. For continued developments special consideration should be given to unit assemblies; subassemblies, premium components, improved materials; simplification of circuits, substitution of components and special processes for mass production.

Reference

"Miniaturization- Crux of Contemporary Product Design," W. H. Hannahs, and B.S. Ellefsen, Electrical Manufacturing, June 1950, P. 86

RELAY CIRCUIT PRACTICES

From a few basic relay circuits are built innumerable automatic control circuits. With a knowledge of the various basic principles involved the electrical designer can take advantage of short cuts when building relay control circuits.

Coil Windings. Five general schemes used in relay coil winding are as follows: (1) A single wound coil wound in one direction only; (2) A double wound coil with magnetic fluxes additive; (3) A double wound coil with magnetic fluxes opposing; (4) A single wound coil with a slow-to-release device; and (5) A single wound coil with a slow-to-operate device. Relays may be made slow-to-release by mounting a copper slug on the heel of the coil core, or by completely covering the coil core lengthwise by means of a copper sleeve. Relays are made slow-to-operate by mounting a copper slug on the armature end of the coil core.

Further arrangements on coil design are double windings on the slow-to-release and the slow-to-operate relays. The release time on a slow-to-release relay can be varied by the spring loading. This type is characteristically fast-to-operate and may have ratios of operate-to-release times of 1:30. The slow-to-operate relay is characteristically slow on both operating and releasing with probably ratios of 4:1.

Contact Arrangement. Several arrangements of relay contacts are commercially available with some of the basic combinations shown in Figure 1. The "make" (normally open) contact is at (A); the "break" (normally closed) contact is at (B); the "break-make" assembly at (C); A "make-before-break" at (D); and a "break-make-before-break" combination at (E). Minor variations such as "break-break" at (G), and the "break-make-make" assembly at (H).

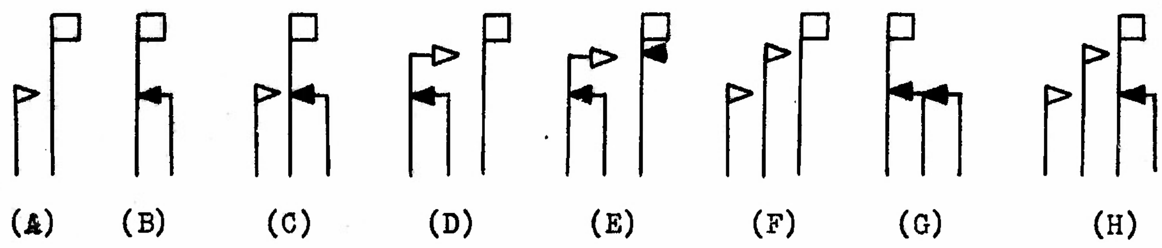


Figure 1

Basic Relay Circuits. The frequently used relay locking circuit is shown in Figure 2 (A). In Figure 2 (B) is a relay having two windings with additive magnetic fluxes of which the Number 1 winding is strong enough to close only the preliminary "X" contact. Upon closure of the "X" contact the Number 2 winding is energized which adds sufficient magnetic pull to close the remaining contacts. Figure 2 (C) shows a double-wound coil with the two windings having opposing magnetic fluxes. Upon the closure of switch A winding Number 1 operates and locks in through contacts 1 and 2. The closing of switch B at any time later will energize winding Number 2 which opposes winding Number 1 causing the relay contacts to open. When the total contact spring load requires more pull than what is available from the Number 1 winding the double relay locking circuit, shown in Figure 2 (D), is used. Upon closure of switch A, contact 1 of relay C closes and the locking circuit is completed through contact 1 of relay D. The closing of switch B operates relay D and opens the locking circuit to relay C.

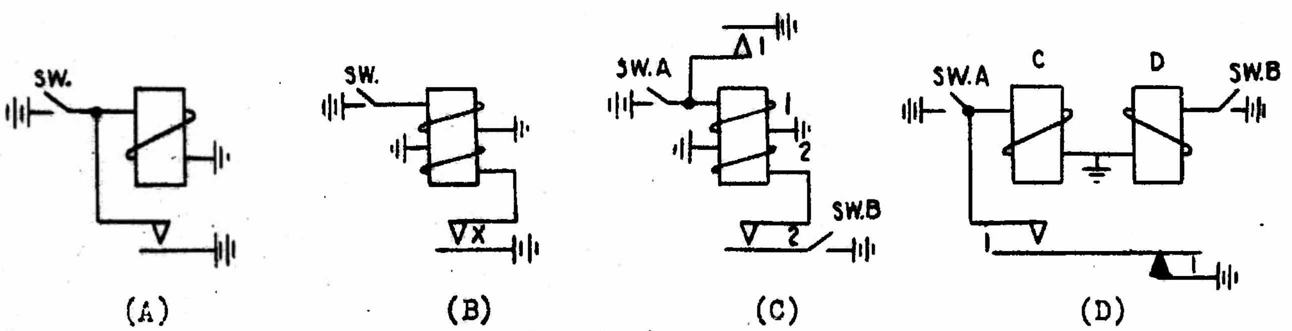


Figure 2

A slow-to-release relay is used when it is desirable to hold the contacts operated during momentary interruptions of energizing current, or for a predetermined period of time after the holding current has been cut off. A slow-to-operate relay is used when it is desired that a relay remain unoperated for a predetermined period of time after the relay winding has been energized. Relay delays may be introduced by short circuited windings, as shown in Figure 3 (A) and (B), which provide slow-to-operate and slow-to-release time delays respectively. However, short circuited windings will not prolong relay functions as long as copper slugs due to the higher resistance in the windings. Other methods used to obtain time delays utilize resistance, capacitance, and inductance. In Figure 3 (C) a capacitor is used to short out the relay coil for a certain period of time till the capacitor has built up sufficient voltage for the relay to operate. Also, when the current is cut off the capacitor will discharge through the relay making it slow-to-release. In Figure 3 (D) resistor R controls the rate of charge to capacitor C upon the closure of switch A, thereby, allowing control over the relay operating time. Once the relay has operated, the capacitor will discharge through R_1, permitting a fast release when switch A is opened. Figure 3 (E) shows a relay circuit arrangement for fast-to-operate and slow-to-release performance.

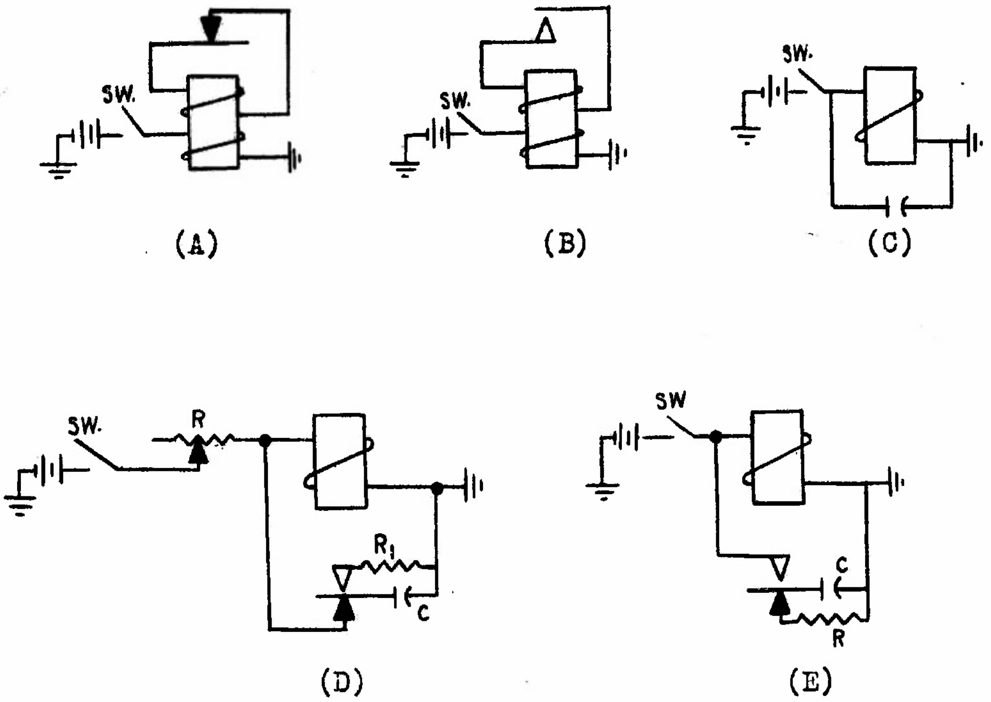


Figure 3

Relay Applications. Relays are found in many pulse absorption schemes, also known as alternate-open-and-close circuits. In Figure 4 is a circuit of this type with a sequence of operations shown. In this particular circuit relays A and B are double-wound with the magnetic fluxes opposing so that neither of the relays will operate when both of its windings are energized.

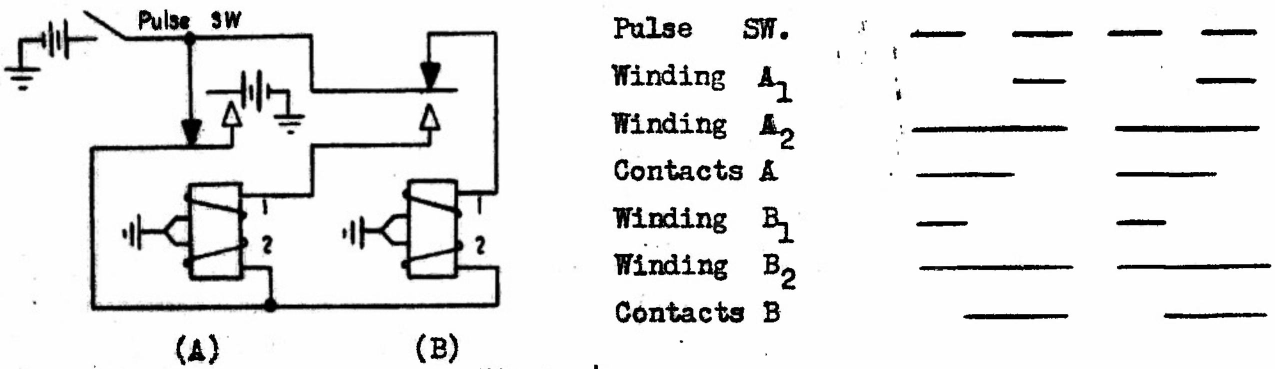


Figure 4

Operation of the circuit in Figure 4 is as follows: Upon first closing of the impulse switch, which is pulsing at a predetermined rate of speed, a circuit is completed to winding number 2 of relay A and to both windings of relay B. Relay A pulls up and locks through its "make" contact in the "make-before-break" contact assembly. Relay B, however, cannot operate until the switch contacts are opened, then its Number 1 winding will be de-energized and the relay will operate under its Number 2 winding. When the switch is closed the second time a circuit is completed to the Number 1 winding of relay A, over the make contact of relay B, causing relay A to restore. On the second opening of the pulse switch relay B will also restore, thus completing one cycle in the circuit operations, which will be repeated over and over as long as the pulsing switch continues in operation.

<u>Reference</u>

Relay Circuit Ideas taken from Telephone Practice, L. F. Crabtree, "<u>Electrical Manufacturing</u>," May 1950, P. 112

TIME DELAY AND COUNTING CIRCUITS

Long Time Delay Relays

When a time delay is needed and the time interval is longer than is practical with flux-decay or capacitor-discharge relays, a more elaborate circuit is necessary. A few of these circuits will be shown along with explanations of their action.

FIGURE I: This relay circuit has a long time delay and uses a DC source and a gas-filled thyratron for its operation. As soon as the switch S is closed, the tube will conduct, but it will not conduct enough for the operation of relay T until the charging of capacitor C_1 has sufficiently raised the grid potential. The time delay depends on the rate at which C_1 is allowed to charge-- the rate depending on the size of C_1 and the adjustment of R_2. Operation of the relay closes contact T_1 so that the tube is out of the circuit and its life is increased. Also, T_2 will close so that C_1 may be discharged for a new cycle. Note that C_1 may not have time to completely discharge if S is closed immediately after opening. This would shorten the amount of the time delay when the duty cycle is increased. It can be varied or completely eliminated as desired by changing the values of R_1 and C_1. The period of time delay can be varied remotely by inserting a transformer secondary into the grid circuit as indicated with an adjustable AC source at the remote location. The effect of the remote grid control is shown in Figure V.

The next three circuits use a convenient 110v AC as a source of power. Relay current is supplied by half-wave rectification in the vacuum tube. The capacitor C_1 is used to hold the relay energized during the negative half of the supply voltage. R_1 prevents short-circuiting of the bias winding. R_2 provides the time delay adjustment.

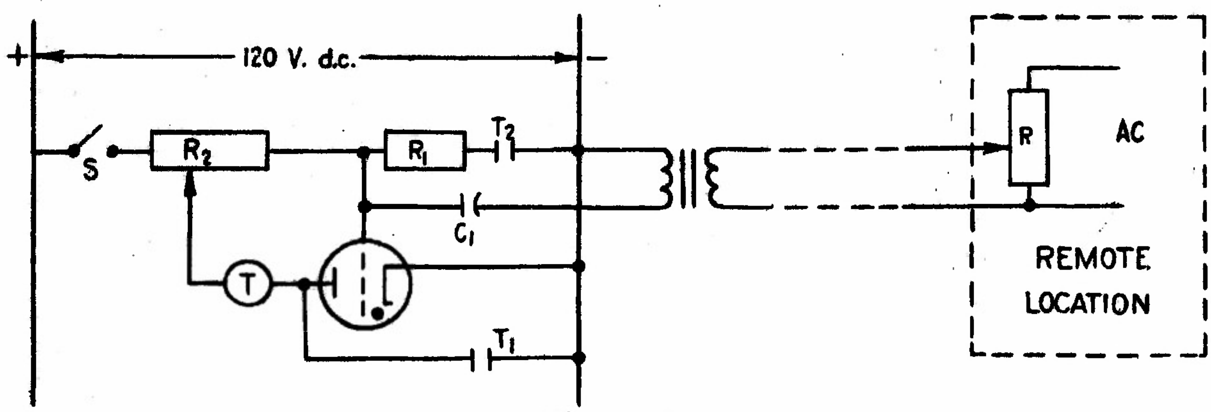


Figure I

Figure II. Relay T is normally energized when the switch S is open. When S is closed, the out-of-phase voltage of the right side of the transformer secondary winding is applied to the grid, biasing it so that the tube does not conduct. The grid will be negative during the half cycle that the plate is positive. Also, C_2 will charge up by means of grid rectification during the positive half cycle of the bias winding. When S is first opened, C_2 must discharge through the variable resistor R_2 before the tube can conduct again. Here again, the time delay can be changed by means of C_2 and R_2.

Figure III. The bias winding is reversed so that T will be energized when S is open and C_2 will be charging by means of grid rectification. When S is closed, the grid will be thrown negative by the charge on C_2. T will drop out but will be picked up again after a time delay depending on the discharge rate of C_2.

Figure IV. Here T is dropped out and C_2 is charging when S is open. When S is closed, the negative side of C_2 is applied to the grid and T remains dropped out until C_2 discharges.

These are only a few of the possible electronic time delay circuits. The methods used in these circuits can easily be adapted to fit the circuit designers need. Further applications of relays will follow in the discussion of counting indicators and stepping relays.

Counting Indicators

Counting indicators describe a condition that existed in the past or

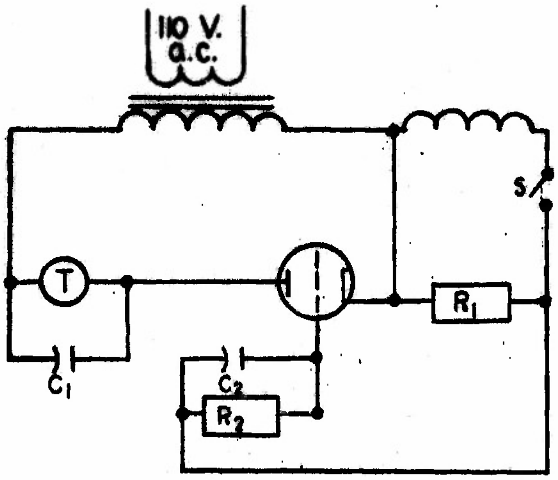


Figure 2

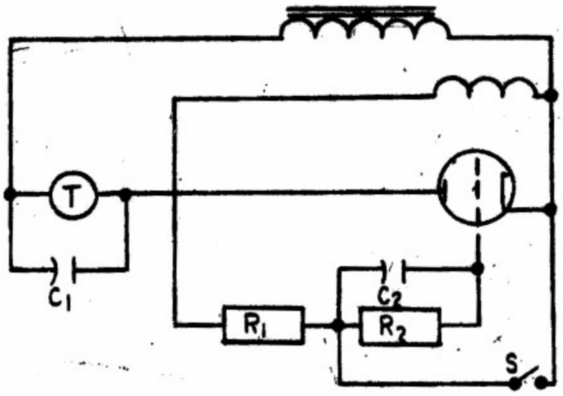


Figure 3

a condition that existed at given time. The latter use will be illustrated in discribing a control for the proper distribution of elevators according to the demand of the people in a large office building.

While it would probably be necessary for a few elevator cars to serve the whole building regardless of their limited use on certain floors, it would certainly be desirable at times for a group of cars to be assigned to the zone of floors having the most calls. If possible, the number of cars assigned to a zone should be in proportion to the number of calls from the zone.

A circuit which will perform the function above is presented in Figure VI. This circuit uses half wave rectifier action to energize the relay T and a holding capacitor C_1 to hold the relay in during the negative half cycle of the supply voltage. The firing of the tube is controlled by a bridge arrangement with the grid and cathode connected across the bridge voltage. The gas-filled tube will fire when its grid is slightly negative. When the bridge is balanced, the cathode and grid are at the same potential and the tube will fire.

Normally closed contacts 2D and 9D are opened by the down buttons of floors 2 to 7. A down call made on the second floor will open the contact 2D and insert R ohms into that leg of the bridge. The bridge is still un-

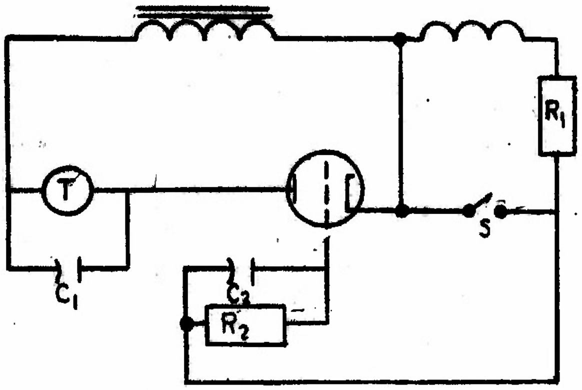


Figure 4

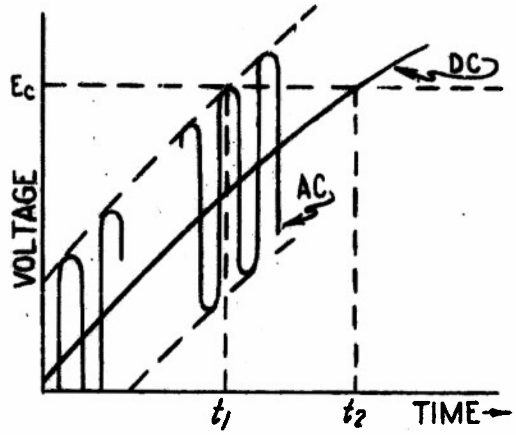


Figure 5

balanced and negative bias still exists on the tube. If down calls are made on both floors 2 and 5, 2R ohms will be inserted into the bottom arm of the bridge and the cathode will be at zero potential. The tube will fire and energize relay T. Relay T will assign a car, say car #1, to the zone. The assignment of car #1 will open contacts to insert 2R ohms into the upper arm of the bridge. Conditions are now as they were in the beginning. This process may be repeated until cars #2 and #3 are assigned to the zone also. This circuit has the effect of assigning a car to the zone for every 2 calls.

The circuit may be altered by changing the values of the resistors on the negative side to fit the quantity to be counted. Large variations in supply voltage do not affect its operation.

The circuit described above measures an existing condition. Figure VII is a simple schematic of a stepping relay that will record past conditions.

The Stepping Relay

When stepping relay coil SS_1 is energized, the push rod L is pulled downward. When coil SS_1 is de-energized, spring SP_1 causes the push rod L to engage rachet N which moves contact arm M one step. The push rod L does not touch the rachet when SS_1 is de-energized and thus, allows only the catch pin of holding relay SS_2 to hold the rachet against the counter clock-wise

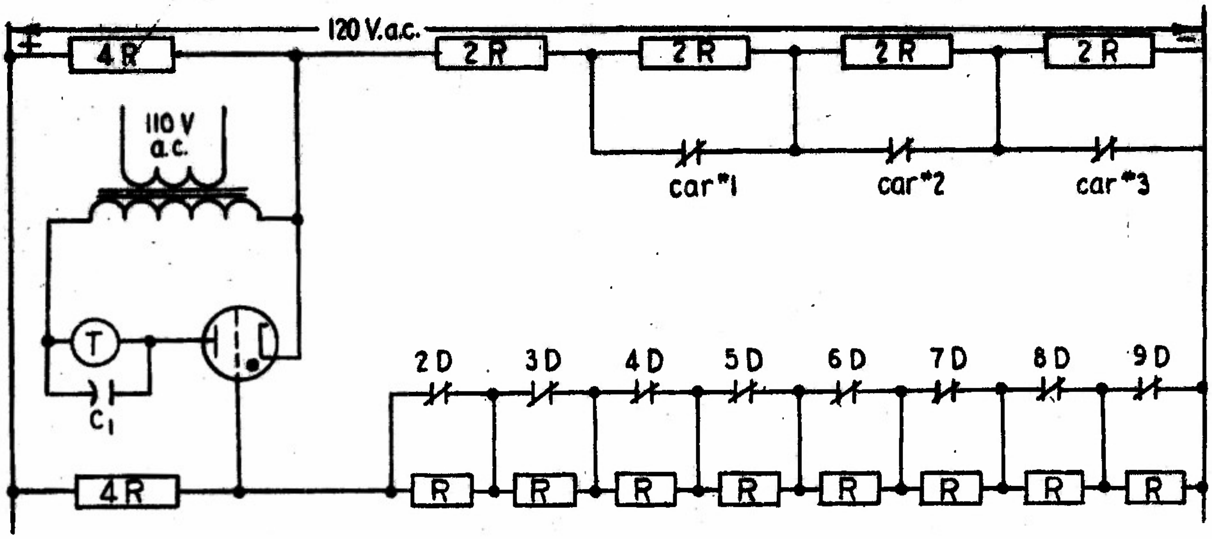


Figure 6

torque of spring SP_2. Thus, the relay must receive a pulse of energy in order to step. Such a pulse is supplied by the momentary contact of the switch S.

When the stepping relay has been pulsed ten times it will be on Contact 11. Relay A will be energized and will lock-in by means of contact A_2. Contact A_1 will energize the holding relay coil SS_2 so that the catch pin is pulled down and the contact arm will reset to Contact 1. Contact 1 energized relay B which opens the normally closed contact B_1 and breaks the lock-in circuit of relay A. The holding pin of SS_2 is released also.

If a second similar stepping relay were set to be pulsed every time relay A is energized, it would make one step for each ten steps of the first relay. Each relay added in this fashion will increase the ability of the circuit to count the total pulses by a factor of 10.

1. Cockrell, W.D., Industrial Electronic Control, McGraw-Hill, N.Y. sec. ed., p 278-282.
2. Esselman and Suozzo, 'Timing Counting Selecting Circuits taken from "Elevator Practice," Electrical Manufacturing, Vol. 46, Sept. 1950, p. 86-89.

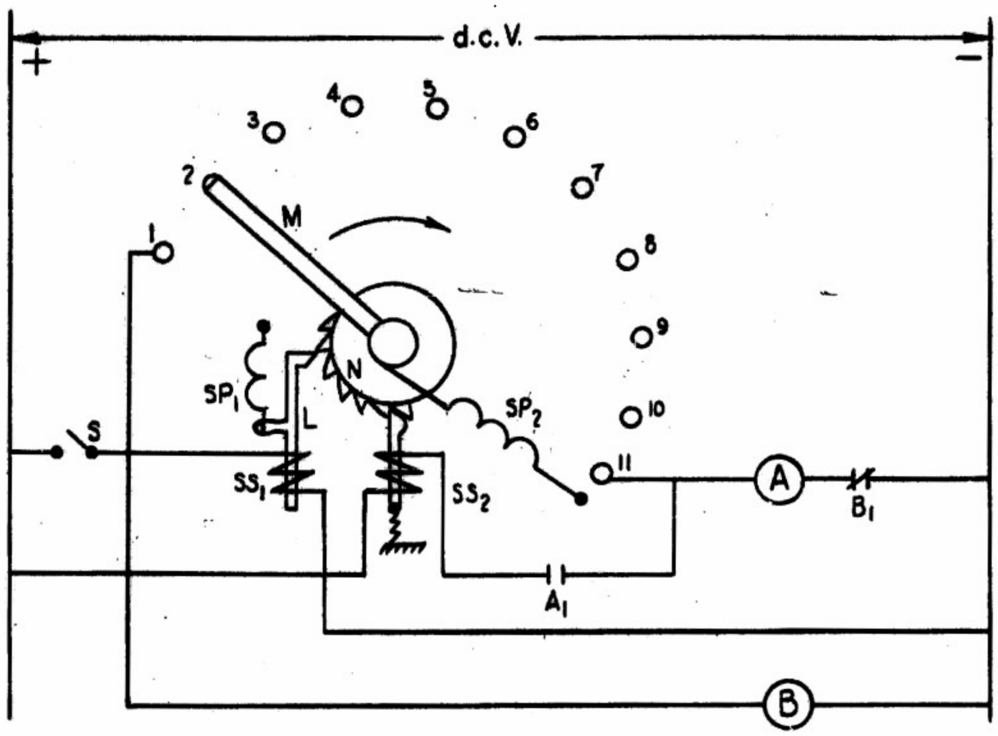


Figure 7

GENERAL FACTUAL DATA

Engineers directly involved in carrying out the subject program are listed below with the number of man-hours applied during the twentieth interim period.

D. L. Johnson ------------120 man-hours

C. W. Jiles--------------120 man-hours

J. E. Tompkins-----------160 man-hours

C. F. Cameron
Director of Project-----150 man-hours

A. Naeter---------------- 40 man-hours

J. C. Richardson--------- 40 man-hours

L. A. Barnes------------- 53 man-hours

Technicians directly involved in carrying out the subject program are listed below with the number of man-hours applied during the twentieth interim period.

J. Owens ---------------- 40 man-hours

M.J. Reynolds------------160 man-hours

A.B. Franks--------------124 man-hours

C.B. Wadsworth----------- 40 man-hours

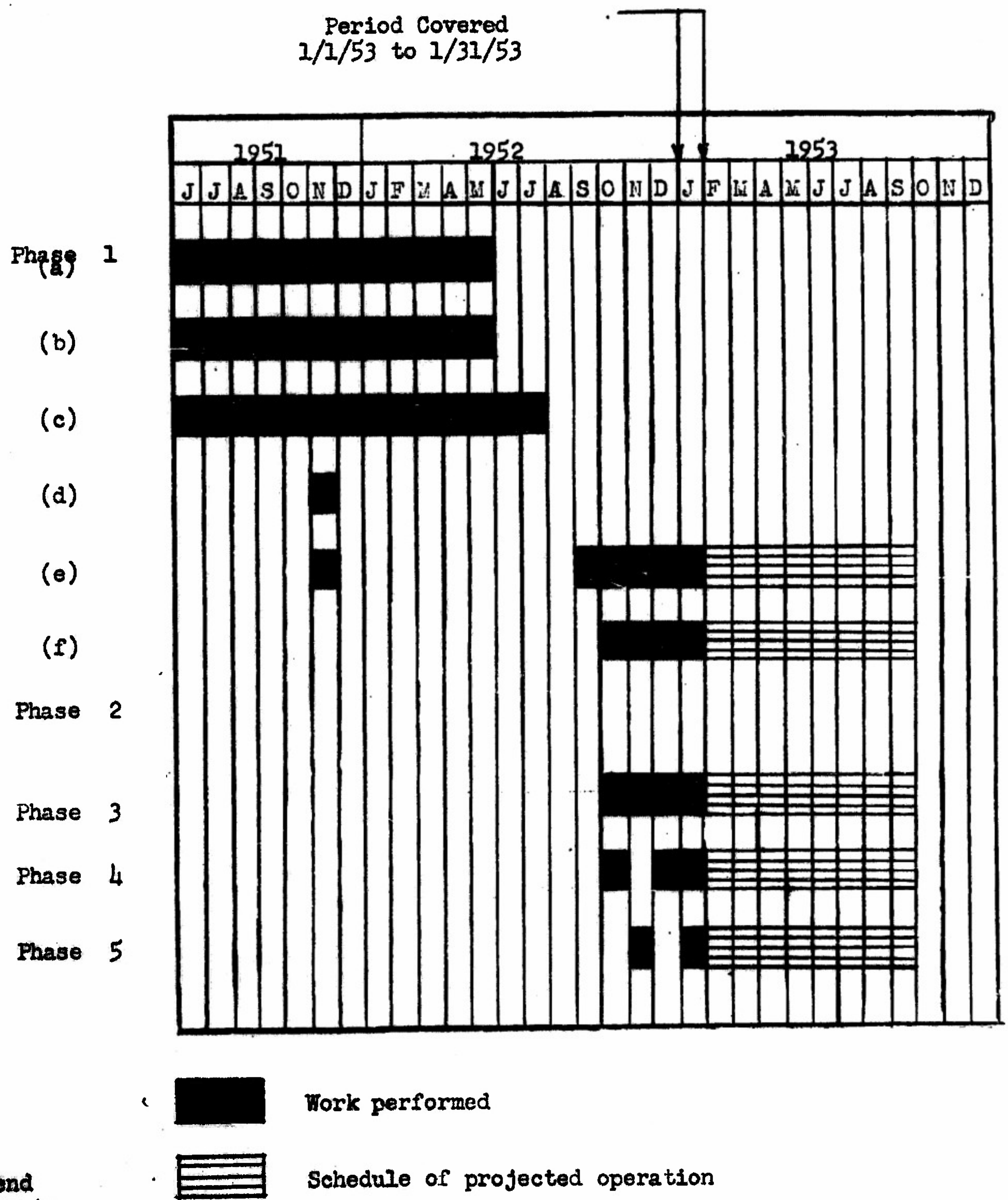
OKLAHOMA A & M COLLEGE

PROJECT PERFORMANCE AND SCHEDULE

Index No. NE111615

Contract NObsr-52423

Report Date 31 Jan. 1953



Legend
Refer to
(SHIPS-R-405
3.1 to 3.1.5)

CONCLUSIONS

I. Before adequate specifications may be written for any relay, there are numerous decisions which must be made. Some of these decisions will involve a necessary and sufficient definition for several of the factors involved in relay operation and application. Another problem which must be settled is the question, "Which scheme will be called a standard for relay terminal connections?" A considerable amount of work has been done on relay dimensions. So far this problem has not been solved. Its solution is required if any degree of interchangeability is achieved.

The foregoing problems are but a few which require some rational solution before a satisfactory set of specification sheets "Standard Relays" may finally be completed.

II. The relation between several seemingly unrelated problems becomes apparent. For instance, a satisfactory definition of terms like, contact bounce, closing time of a N.C. relay, opening time of a N.C. relay, also N.O. relay. What is the closing time of a relay with Form C contacts? These questions must have a satisfactory answer before adequate specification can be prepared for all relays.

III. In this report under the subject of Contact Bounce, an attempt is made to show by illustration some definitions relative to relays. To have sufficient relay characteristics available for study, it is necessary to have adequate test equipment. A list of desired equipment is being prepared.

PROGRAM FOR NEXT INTERVAL

I. Work on Relay Standards, Relay Test Code and Relay Specifications will continue.

II. In this report as well as the previous report, there is some material on Proposed Specifications for Adopted Stock Relay or Standard Relays. Haste in preparation of this material is not satisfactory because the Relay Standards and Relay Test Code should be completed first.

III. It is proposed to have additional meetings for representative of Relay Manufactures and Relay Users.